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THE ENERGY COST OF LEVEL WALKING AND RUNNING IN FEMALES AND MALES

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "The Energy Cost of Level Walking and Running in Females and Males" submitted by Yagesh Bhambhani in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

The primary purpose of this study was to compare the energy costs of walking and running a distance of one kilometre in females and males at the individuals optimal (most comfortable) speed for each activity. The secondary purpose was to compare the females and males energy cost of walking and running a distance of one kilometre at their optimal speeds.

Twenty-four active volunteers, 12 female and 12 male, were subjected to 4 testing sessions. In session 1, the maximum oxygen uptake was predicted using a submaximal bicycle test and the percentage of body fat was estimated by the hydrostatic method. In session 2, the optimal speeds of walking and running on a level treadmill were subjectively determined. In sessions 3 and 4, the following data was collected. First, the oxygen consumed during 5 minutes of standing 'at ease' on the treadmill was determined using a Beckman Metabolic Measurement Cart (MMC) and the average standing oxygen consumption per minute was calculated. Second, the oxygen consumption was measured during the entire exercise (walking or running) period as well as the post exercise period until the oxygen consumption per minute reached the average standing value determined prior to the exercise. Third, during the exercise the subject was filmed with a movie camera set up directly behind the subjects's back. Filming was done after the subject completed 25% and 75% of the required distance. On each occasion 3 strides were filmed and the film was subsequently analyzed to determine the average vertical lift per step of the body. Finally, during the middle of the exercise the step frequency was counted manually for 2 minutes from which the

step frequency per kilometre of distance travelled was calculated.

The data collected was subjected to a two-way analysis of variance with repeated measures on one factor and the significant 'F' ratios were subjected to the appropriate 't' test to locate the differences.

The results indicated that for both sexes, the gross and net energy costs of running were significantly greater than those of walking ($P < .001$). This was true regardless of whether the energy costs were expressed in units of distance travelled, Kcals/kg/km, or in units of a single step of the activity, cals/kg/step. The sex comparisons revealed that for both these methods of comparison, there were no significant differences between females and males in the gross or net energy costs of walking ($P > .10$). However, the gross and net energy costs of running the distance of one kilometre proved to be significantly higher in females than in males ($P < .05$). It was suggested that this was due to the characteristic running gait of the females. These differences between the sexes ceased to exist when the energy costs were expressed in units of a single step of the activity, cals/kg/step ($P > .10$). This was probably because there was no significant difference between females and males in the vertical lift per running step ($P > .10$).

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CHAPTER 1

STATEMENT OF THE PROBLEM

Introduction

Since exercise is highly recommended for the purpose of weight reduction (48, p. 175), it is imperative that we know how different activities compare with regard to their metabolic costs. Two activities which numerous individuals indulge in for this purpose are walking and running.

Numerous investigators have studied the relationship between the metabolic cost and speed of walking and/or running and have derived equations (7,8,22,23,28,57,62,65,73,77,80) and nomograms (54,71,79) that could predict this value fairly accurately. Some of these investigations have shown that:

(a) There is an optimal speed of walking at which the energy expenditure per unit distance travelled is a minimum (7,8,18,23,57,65, 73,80). This speed is usually at or very close to the speed which the subject chooses 'most naturally' or finds 'most comfortable' (65) and is due to an optimal step frequency (23).

(b) There also may exist an optimal speed of running (56) at which the energy expenditure per unit distance travelled is a minimum. This is due to an optimal stride length (45,49) which is usually the one that the

subject selects most 'freely' or 'naturally'.

Comparison Between the Metabolic Cost of Walking and Running A Unit Distance.

The studies that have compared the metabolic costs of walking and running a unit distance at similar speeds generally agree that at low speeds it is more economical to walk than to run, while at high speeds the reverse is true (9,54,58,71,73,79). The crossing point or critical speed for the change in economy from walking to running varies between individuals and is normally within the speed range of 8 to 9 kilometres per hour. In other words, the energy cost of walking a unit distance of say 1 kilometre, below a speed of 8 to 9 kilometres per hour, is less than that of running the same distance at a similar speed. At speeds above 8 to 9 kilometres per hour, the energy cost of running a unit distance is less than that of walking the same distance at a similar speed. However, within the speed range of 8 to 9 kilometres per hour, the energy cost of walking and running a unit distance is equal. Astrand and Rodahl (4) seem to agree with these investigators when they state (p. 473, p. 543) that the energy cost of walking briskly at the less economical speed of 10 kilometres per hour is equivalent to that of running the same distance at the more economical speed of 14 kilometres per hour.

The Metabolic Cost of Walking and Running a Unit Distance: A Comparison Between Males and Females.

Physiologists generally agree that the Basal Metabolic Rate of adult

males is approximately 6 to 7 percent higher than that of adult females (29). However, whether this difference between the sexes persists in the metabolic cost of doing muscular work such as walking or running is controversial. Researchers that have investigated this aspect of metabolic function have proposed three different views if the energy cost per unit distance travelled is expressed in terms of gross body weight:

a) There is no real difference between the sexes in the gross (7, 30, 53, 65, 80) or net (7, 33, 39) metabolic cost of walking or running.

b) The gross metabolic cost of walking or running is significantly greater for males than for females (10, 29, 39).

c) The gross (12, 46) or net (46) metabolic cost of walking or running is significantly greater for females than for males.

However, if the energy cost per unit distance travelled is expressed in terms of lean body weight, then the following two suggestions have been made:

a) There is no real difference between the sexes in the gross metabolic cost of walking or running (29).

b) The gross and net metabolic cost of walking or running is significantly greater for females than for males (46).

The Problem

In 1974, Howley and Glover (46) used an unorthodox method for comparing the energy costs of walking and running. In 8 female and 8 male subjects, they determined the energy cost of walking at a constant speed and that of running at the subject's 'most natural'speed. Their results

indicated that the energy cost of running a distance of one mile was approximately eighty percent more expensive than that of walking the same distance under similar testing conditions. The metabolic measurements in their study, however, were carried out under steady state conditions of exercise and therefore, no repayment of the oxygen deficit, incurred during the initial stages of exercise, was considered in calculating the metabolic costs of the activities. Although there is sufficient evidence to show that under such conditions the oxygen supply and demand are equal (55, 69, 74), there is some evidence indicating that the oxygen deficit incurred during the initial stages of exercise and the oxygen debt that is repaid during recovery from it are not exactly equal (1, 20). A study by Asmussen (1) showed that the oxygen debt was significantly greater than the oxygen deficit for an exercise period lasting more than three minutes. Christensen and Hogberg (20) have also found the oxygen deficit to be approximately 50 percent of the oxygen debt in moderate intensity work and even less at more severe work loads. Since an oxygen deficit is usually incurred during the initial stage of an exercise bout of moderate intensity (55, 69), it seems that the metabolic cost calculated from the volume of oxygen consumed under steady state conditions is underestimated. A more accurate value will be obtained by calculating the metabolic cost from the total volume of oxygen consumed during the exercise period as well as the oxygen debt that is repaid subsequently.

Studies that have observed differences between females and males in the metabolic cost of walking or running a unit distance have offered the following explanations:

(1) Males expend a greater amount of energy than females while walking because (a) they have a thirteen per cent higher standing metabolic cost which is reflected in the gross energy cost of walking (39), (b) their longer stride length apparently results in a greater vertical lift of the body thereby increasing their gross energy expenditure (10).

(2) Females expend a greater amount of energy than males while running because their slower running speed apparently causes them to raise their bodies vertically to a greater height thereby increasing their gross energy expenditure (12,46).

The studies that have offered 'increased vertical lift of the body' as the reason for the greater metabolic cost of both males and females did not actually measure the vertical lift of the body.

The primary purpose of this study was to compare the metabolic cost of walking and running a distance of one kilometre while the subjects were allowed to choose their optimal speeds, taking the total volume of oxygen consumed during the exercise as well as recovery periods into consideration. The secondary purpose of this study was to compare females and males for the metabolic cost of walking and running a distance of one kilometre at their optimal speeds and to investigate whether the differences, if any, were due to diff-

erences in (a) the metabolic cost of standing, (b) the vertical displacement of the body and (c) the amount of internal work done as indicated by the step frequency.

Hypotheses

It was hypothesized that:

(1) a) There would be no significant difference in the net metabolic cost of walking and running a distance of one kilometre when the female subjects were allowed to choose their optimal speeds.

b) There would be no significant difference in the net metabolic cost of walking and running a distance of one kilometre when the male subjects were allowed to choose their optimal speeds.

For both the groups of subjects,

$$H_o: \mu_w = \mu_r,$$

where w = walking and r = running.

(2) a) There would be no significant difference between females and males in the net metabolic cost of walking a distance of one kilometre when the subjects were allowed to choose their optimal speeds.

b) There would be no significant difference between females and males in the net metabolic cost of running a distance of one kilometre when the subjects were allowed to choose their optimal speeds.

For both these activities,

$$H_o : \mu_f = \mu_m,$$

where f = female and m = male.

For each of these hypotheses, the metabolic cost will be expressed as Kcals/Kg/Km. of distance travelled.

Limitations of the Study

(1) Variations in the calibration of the metabolic cart and the treadmill speed between testing sessions.

(2) That the speed of walking and running selected by each subject was in fact the optimal speed for that activity.

(3) Diet of the subjects immediately prior to testing which could have effected the metabolic cost of the activity being measured due to the Specific Dynamic Action of the foodstuffs.

(4) Physical activity of the subjects immediately prior to testing which could have effected the metabolic cost of the activity being measured.

(5) The Caloric equivalent of one litre of oxygen was restricted to the non protein respiratory quotient values.

Delimitations of the Study

(1) The study was delimited to 12 female and 12 male volunteers.

(2) Comparison between the metabolic cost of walking and running was made only at the optimal speed of each of these two activities.

(3) Any differences in the metabolic cost of walking and running

between females and males were in fact due to differences in either the standing metabolic cost, external (vertical) work or internal (muscular) work and not due to any other variables that are known to effect metabolic rate.

Definition of Terms

(a) Walking - forward linear motion of the body accompanied by a period of double leg support in every step.

(b) Running - forward linear motion of the body accompanied by a period of momentary suspension in the air during every step.

(c) Optimal Speed - the speed of walking or running which the subject chose most naturally. This was supposedly the speed at which the energy expenditure was a minimum (expressed in metres per minute).

(d) Step Frequency - the total number of times the left and right heel made contact with the ground (expressed as steps per minute).

(e) Step Length - ratio between the optimal speed and the step frequency (expressed as metres per step).

(f) Vertical Lift - height by which the body was displaced vertically during a walking or running stride, as measured by cinematographic analysis of the movements of the fifth lumbar vertebra.

(g) Kilocalorie - the quantity of heat required to raise the temperature of one kilogram of water by 1^{o} Celsius (abbrev-

iated as Kcal).

(h) Gross Energy Cost - the energy cost of walking or running which included the energy cost of standing and recovery.

(i) Net Energy Cost - the energy cost of walking or running obtained by subtracting the energy cost of standing from the gross energy cost.

CHAPTER 2

REVIEW OF LITERATURE

The Metabolic Cost of Indoor Walking

In 1915, Benedict and Murschhauser (6) extensively reviewed twenty studies done between 1859 and 1914 that determined the metabolic cost of walking using the technique of open circuit spirometry. According to them, these studies indicated that the metabolic cost of walking indoors, either on a floor or on a treadmill, increased with the speed of movement. This value ranged from a low of 0.308 Kcals/Kg/Km at a speed of 4.75 kilometres per hour (79.2 metres/minute) obtained by Amar in 1910 to a high of 1.169 Kcals/Kg/Km at a speed of 10.64 kilometres per hour (177.3 metres/minute) obtained by Caspari in 1905. Generally speaking, when the speed of walking was between 4.8 to 5.4 kilometres per hour (80 to 90 metres/minute), the metabolic cost varied between 0.3 to 0.7 Kcals/Kg/Km, the average being approximately 0.55 Kcals/Kg/Km. These values are comparable with subsequent studies that have determined the metabolic cost of walking at different speeds and hence can be quoted even today.

Relationship Between the Metabolic Cost and Speed of Walking

The more recent studies in this area have investigated whether there is a definite trend between the speed of walking and its metabolic

cost. Some authors claim that the relationship between these two parameters is curvilinear (7,8,18,22,23,28,32,38,57,60,65,73,78,80) while others say that it is either partly linear, partly curvilinear (9,33,58,62) or that there is no definite relationship (27,79).

Ralston (65) studied the relationship between the metabolic cost and speed of walking in 19 subjects, 12 male and 7 female, under steady state conditions. He found the existence of a linear relationship between the net energy expended per minute and the square of the walking velocity (a curvilinear relationship between the metabolic cost and speed of walking). The regression equation that he derived for predicting the net metabolic cost was:

$$E_w = 29 + 0.00053V^2$$

where E_w = Kcals/Kg/min.

and V = speed in metres per minute.

When he plotted the net energy expended per unit distance travelled (E_w/V) against the speed of walking, he obtained a curve which took the form of a hyperbola as shown in Figure 1. This indicated to him that there existed an optimal speed at which the energy expended per unit distance travelled was a minimum. This optimal speed in his study averaged to 74 metres per minute (4.44 kmh) requiring a gross energy equivalent of 0.78 Kcals/Kg/Km. Ralston also proceeded to show that the optimal speed of walking varied between individuals and was usually at or very close to the speed which the subject chose 'naturally' or which he or she subjectively regarded as 'most comfortable'.

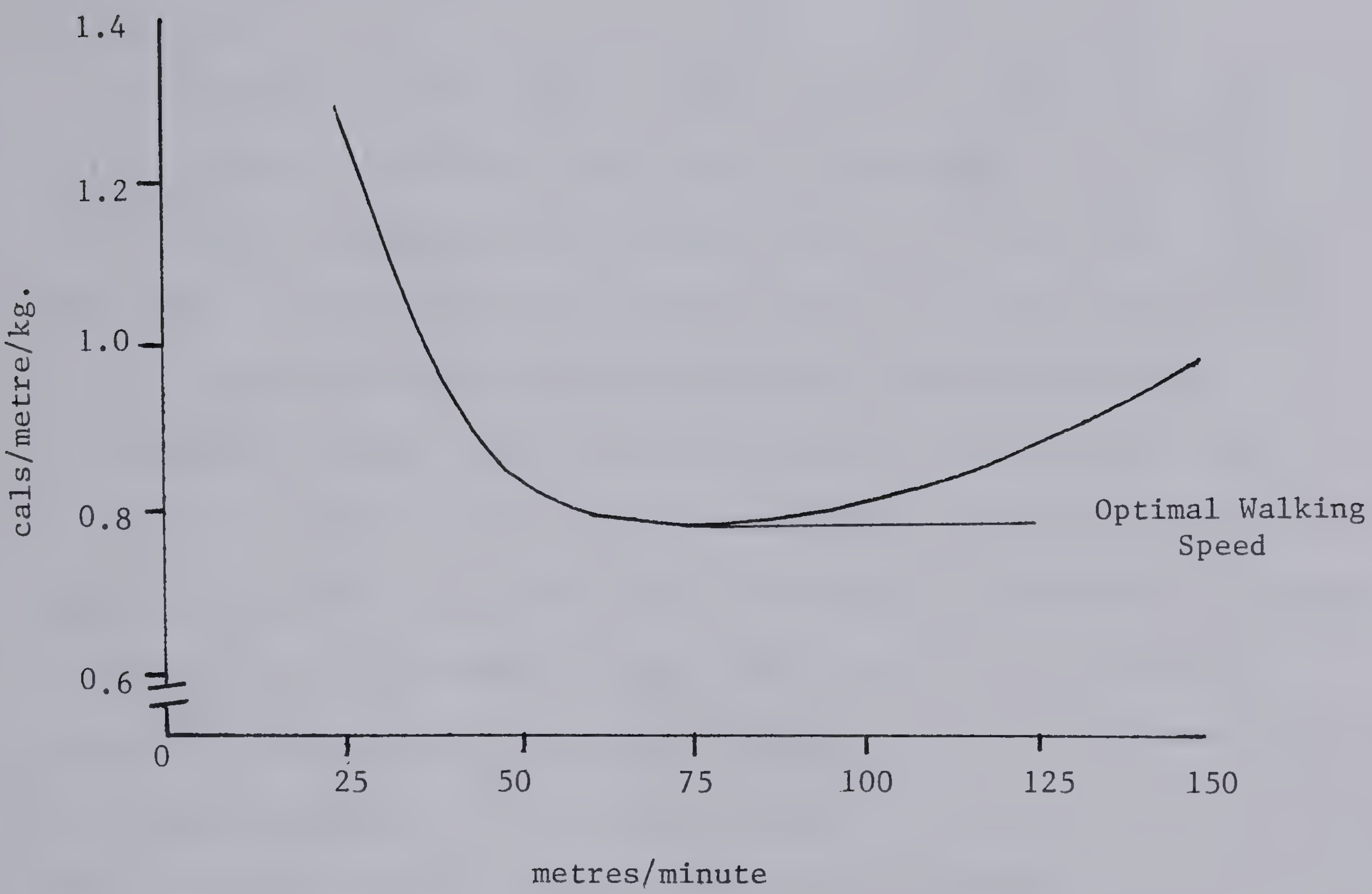

Figure 1 Relationship Between the Energy Expended Per Unit Distance Travelled and Speed of Walking as Obtained by Ralston.[1]

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[1] Ralston, H.J.; Energy Speed Relation and Optimal Speed During Level Walking; Internationale Zeitschrift for Angewandte Physiologie Einschliesslich Arbeits Physiologie, Vol. 17: 277-83, 1958.

The studies carried out by Blessey, et al. (7), Bobbert (8), Cavagna, et al. (18), Corcoran and Brengelmann (22), Cotes and Meade (23), Donovan and Brooks (28), McDonald (57), Van der Walt and Wyndham (73), as well as Zarrugh, et al. (80) have all shown similar results. However, the regression equations as well as the optimal speeds that these authors obtained were quite different. Table 1 shows these in tabular form.

The studies by Bobbert (8) as well as Cotes and Meade (23) have derived different regression equations for each subject which implies that the rate of change of energy expenditure with speed varies between individuals. Donovan and Brooks (28) obtained a different equation to predict energy expenditure for each speed that they investigated. The equations given by Ralston (65) and Blessey (7) were derived from the average values of all the subjects tested in their respective studies (19 and 40 respectively, male and female). The equation suggested by Van der Walt and Wyndham (73) was the only one, among the studies reviewed, to include both mass (M) and energy (MV^2) terms. McDonald's (57) equation was based on the average values of 19 subjects obtained from 9 different studies while the one proposed by Zarrugh, et al. (80) was based on the average values of 86 subjects (57 male and 29 female) from four different studies. According to both these studies, the gross energy cost of walking reached a minimum value of 0.8 Kcals/Kg/Km at a speed of 80 metres per minute (4.8 kmh).

Cotes and Meade (23) observed that the total metabolic cost was linearly related to the total vertical lift of the body, which in turn

Table 1 - Regression Equations and Optimal Speeds of Walking Obtained By Different Investigators.

Investigators	Year	Regression Equation	Optimal Speed Meters Per Minute
Ralston	1958	$E_w^{(1)} = 29 + .00053V^2$	74
Bobbert	1960	a) $E_w^{(1)} = 32.33 + .00476V^2$	82.5
		b) $E_w^{(1)} = 32.63 + .00455V^2$	84.5
Cotes and Meade	1960	Varies between subjects.	60.2
		$E_{O_2}^{(2)} = av^2 + b$ (5)	
McDonald[6]	1961	$Log_{10}H^{(4)} = av+bv^2+c$ (5)	80
Cavagna, et al.	1963		66.67
Corcoran and Brengelmann	1970	$E_{O_2}^{(2)} = 0.336V^2+6.15$	83.33
Van der Walt and Wyndham	1973	$\dot{V}_{O_2}^{(3)} = .00599M+.000366MV^2$	67.5
Zarrugh, et al.[7]	1974	$E_w^{(1)} = 32+.005V^2$	80
Blessey, et al.	1976	$E_{O_2}^{(2)} = 7.55+.000811V^2 \pm 2.33$	81.5
Donovan and Brooks	1977	Varies with speed	
		$y^{(4)} = ae^{bx}$ (5)	

Legend

(1) E_w = cals/kg/min.

(2) E_{O_2} = O_2 ml/kg/min.

(3) V_{O_2} = O_2 litres/min.

(4) H,y = Kcals/min.

(5) = general equations

(6)= average of earlier studies

(7)= average of 4 studies

M = mass in kilograms

v = speed in kilometres per hour

V = speed in feet per second

was linearly related to the square of the effective step length. In other words, there was a linear relationship between the metabolic cost of walking and the square of the effective step length. These researchers also showed that the optimal speed of walking was due to an optimal step frequency rather than an optimal step length. An optimal step frequency suggests that there may be a speed of muscle contraction at which the energy expenditure is a minimum.

Cavagna, et al. (18,19) did not use respiratory measurements to determine the metabolic cost of walking. Instead they calculated the actual work done which was given by the sum of the external and internal work performed. The external work was computed as the total of the forward, vertical and lateral (which was negligible) work, while the internal work was determined from the kinetic energy measurements of the limbs as suggested by Fenn (34). They found that the net energy cost of walking a unit distance reached a minimum value of 0.48 Kcals/Kg/Km at a speed of 4 kilometres per hour (66.67 metres per minute) despite the fact that the total external work was a maximum at this speed. The increased energy costs at the lower and higher speeds was due to an increase in the internal or muscular work. Contrary to the findings of Cotes and Meade (23), they showed that the vertical displacement of the body increased with step length only up to a point. Once the latter reached 0.9 to 1 metre, the vertical lift remained constant.

Workman and Armstrong (77) also observed a curvilinear relationship between the metabolic cost and speed of walking. This curve was described by an equation of the fifth order.

$$VO_2 = 0.00065x^5 - 0.0108x^4 - 0.315x^2 + 0.65x$$

where VO_2 = oxygen uptake in litres per minute

and x = speed in miles per hour.

Although they did not find a linear relationship between the metabolic cost and square of the walking velocity, they however did observe an optimal speed of walking at 53 metres per minute (3.18 kmh).

The efficiency of walking is given by the ratio between the distance travelled and the energy expended in travelling that distance (28). A hyperbolic relationship between the metabolic cost and speed of walking implies that as the speed increases, the efficiency also increases until the optimal speed is reached. At speeds higher than the optimal one, the efficiency continually decreases because the metabolic cost increases by a greater proportion than the distance travelled. Donovan and Brooks (28) felt that the declining efficiency at the higher speeds may be due to a shift from the utilization of the more efficient red, slow twitch skeletal muscle fibres to the less efficient white, fast twitch fibres.

Contrary to the findings of the studies so far reviewed, the evidence presented by Boje (9), Falls and Humphrey (33), Passmore and Durnin (62) as well as Menier and Pugh (58) indicates that the relationship between the metabolic cost and speed of walking is partly linear and partly curvilinear. The former three studies have shown that the relationship was linear up to a speed of 6.5 kilometres per hour (108.33 metres per minute). In other words the efficiency or the cost per unit distance travelled remains constant up to a speed of 6.5 kilometres per

hour. Passmore and Durnin (62) suggested the following equation to predict the metabolic cost of walking within the speed range of 3 to 6.5 kilometres per hour (50 to 108.33 metres per minute).

$$C = 0.8V + 0.5$$

where C = Kcals/min.

and V = kilometres per hour.

At velocities above 6.5 kilometres per hour, the metabolic cost increased more rapidly than the distance travelled causing the relationship to become curvilinear thereby decreasing the efficiency. The latter study (58) revealed just the opposite - that the relationship was curvilinear up to a speed of 8 kilometres per hour (133.33 metres per minute) and linear between 8 kilometres per hour (133.33 metres per minute) and 14.5 kilometres per hour (241.66 per minute).

The studies by Dill (27) and Wyndham, et al. (79) were unable to establish any particular trend between the metabolic cost and speed of walking, but they did indicate a declining efficiency as the latter increased.

The Metabolic Cost of Indoor Running

Unlike walking, the majority of the literature on running indicates that its metabolic cost does not vary with speed (9,12,17,33,54,56,58, 60,71,79). Boje (9) and Margaria (54) claimed that the net value averaged approximately 1 Kcal/Kg/Km. of distance run for most individuals, but according to the former it could range between 0.86 Kcal/Kg/Km. and 1.15 Kcal/Kg/Km. Passmore and Durnin (62) felt that variations between

individuals in the metabolic cost of running were due to differences in the degree of training and the efficiency of the subject.

Relationship Between the Metabolic Cost and Speed of Running

Research in this area indicates that these two parameters can be linearly (12, 17, 33, 54, 56, 58, 60, 71, 79), curvilinearly (38, 49, 68, 73) or indefinitely (27) related. As well, there is some evidence indicating that the type of relationship obtained is dependent on the testing environment (64) or the method by which the energy cost is determined (20).

The linear relationship between the metabolic cost and speed of running appears to be true within the speed range of 1.6 kilometres per hour (26.66 metres per minute) to 22 kilometres per hour (366.66 metres per minute). Shephard (71) studied 24 male subjects running between the speed of 1.6 kilometres per hour (26.66 metres per minute) to 8.9 kilometres per hour (148.33 metres per minute) and found the linear relationship between the gross metabolic cost and speed of running to be highly significant. He devised a nomogram to predict the metabolic cost of running within the speed ranges that he investigated and found the coefficient of variation to be within 7.7 percent to 12.8 percent. Margaria (54) observed a similar relationship when he examined 2 male subjects running at the higher speeds of 9 kilometres per hour (150 metres per minute) to 22 kilometres per hour (366.66 metres per minute).

This linear relationship at the higher speeds of running has also been observed by Boje (9), Bransford and Howley (12), Cavagna, et al. (17), Falls and Humphrey (33), Mayhew (56), Menier and Pugh (58), Ogasawara (60) and Wyndham, et al.(79).

Because of the tremendous degree of linearity even at the maximum speeds that he investigated, Margaria (54) felt justified in extrapolating values of caloric expenditure at even greater speeds which would involve an anaerobic state and the contraction of an oxygen debt. As a result, he devised a nomogram which could be used to predict the energy cost of running within the range of 8 kilometres per hour to 28 kilometres per hour and found it to be accurate within ±3 percent. Boje (9) who observed a linear relationship between the speeds of 8 kilometres per hour to 18 kilometres per hour felt that at higher speeds the metabolic cost of running would increase because the subject's overall efficiency would decrease when he or she approached his or her maximum working capacity.

As has been seen earlier, a linear relationship between the metabolic cost and speed of running implies that the efficiency remains constant. In other words, the energy cost of running a unit distance does not vary with speed. Cavagna, et al. (17) have shown that his was because the total work done per unit distance, given by the sum of the internal and external work, was independent of speed. In order to achieve this constant efficiency, the external work increased linearly with the running speed (19) while the internal work, calculated from kinetic energy measurements of the various limbs as suggested by Fenn (34), increased as the square of the running velocity (16). Of the two major components of

the external work, the vertical work done per unit distance actually decreased with increasing speed (unlike walking) while the forward work per unit distance increased with speed thereby maintaining the overall linear relationship between the external work done and running speed (17).

Mayhew (56) in addition to his claim of linearity also claimed that there was an optimal speed of running at which the energy expended per unit distance travelled was a minimum. When he plotted the energy cost per kilogram per kilometre of distance run against running speed between 8 kilometres per hour and 18 kilometres per hour (Figure 2), he was able to obtain two regression lines that intersected at a speed of 11.1 kilometres per hour (185 metres per minute), which he claimed was the optimal running speed. An optimal speed of running however is not possible if the relationship between the metabolic cost and speed of running is truly linear and, therefore, the author seems to be contradicting himself in this study. It should be noted, however, that the subjects in this study were highly trained distance runners who could easily have maintained a uniform cost of running throughout each of the six minute test periods at the various speeds that they were subjected to. The suggestion that there exists an optimal speed of running, however, should not be completely disregarded in light of some work done by Hogberg (45) and Knuttgen (49). Both these authors demonstrated that for each running speed, there was a step length at which the energy expenditure was a minimum (Figure 3). This optimal step length varied between individuals and was usually the one which the

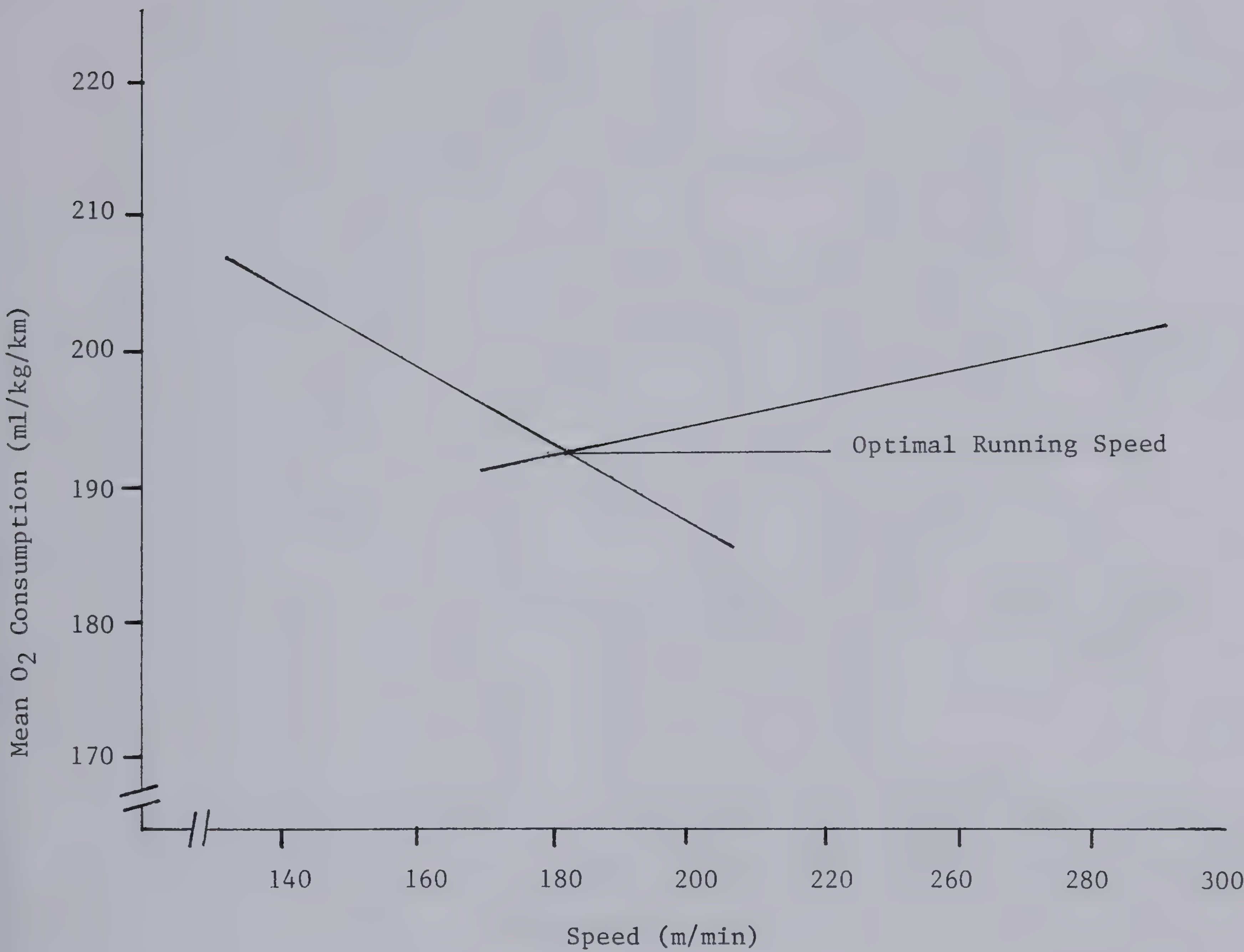

Figure 2 Relationship Between Oxygen Consumption Per Unit Distance Travelled and Speed of Running as Obtained by Mayhew.[1]

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[1] Mayhew, J.L.; Oxygen Cost and Energy Expenditure of Running in Trained Runners; British Journal of Sports Medicine, Vol. 11: 116-21, 1977.

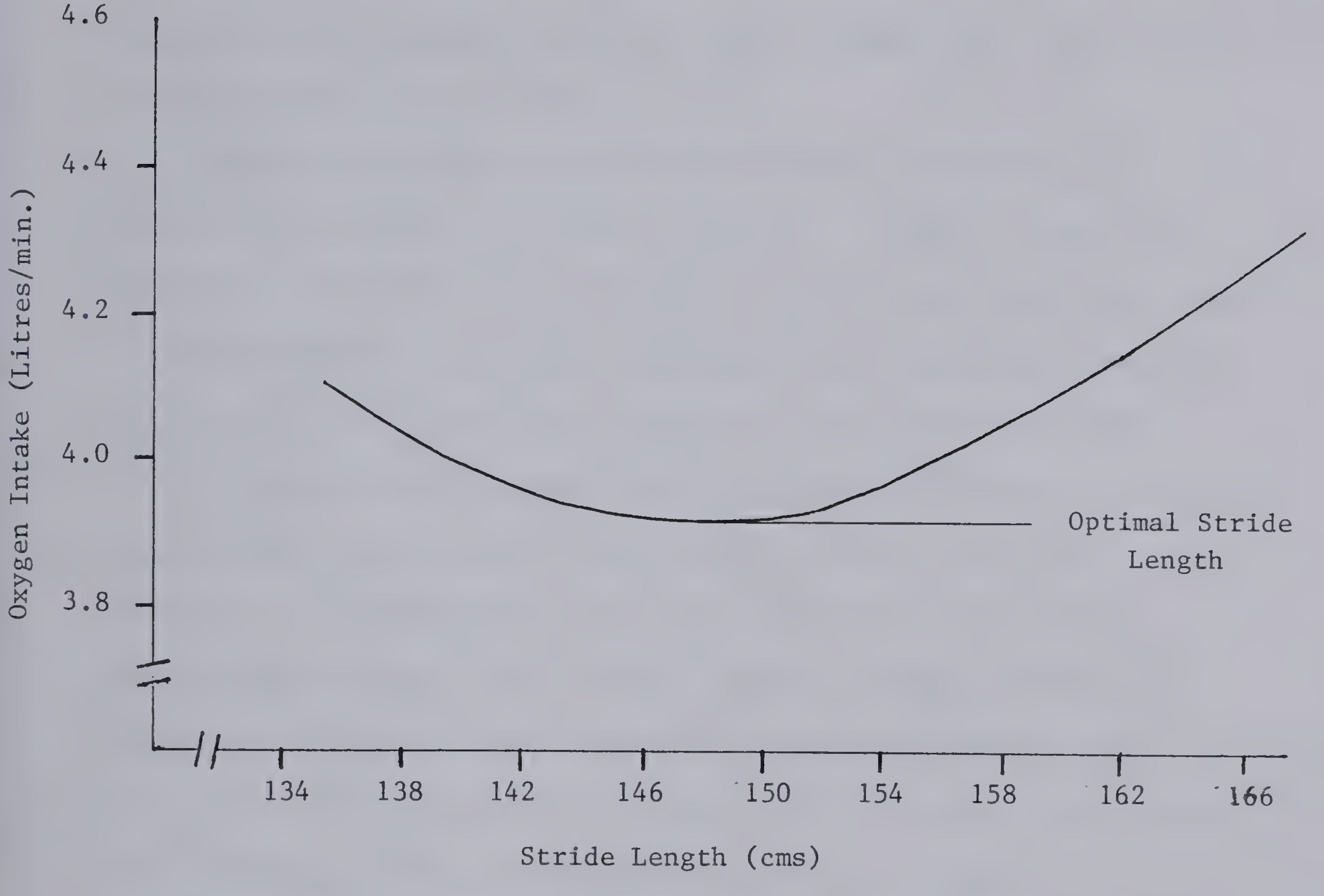

Figure 3 Relationship Between the Oxygen Intake and Different Stride Lengths for a Given Speed as Obtained by Hogberg.[1]

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[1]Hogberg, P.; How Do Stride Length and Stride Frequency Influence the Energy Output During Running; <u>International Zeitschrift for Angewandte Physiologie Einschliesslich Arbeits Physiologie</u>, Vol. 14: 437-41, 1952.

subject chose most 'freely' or 'naturally'. Since running speed is given by the product of the step length and step frequency (50), it is, therefore, not surprising that Mayhew (56) has suggested an optimal running speed.

A curvilinear relationship between the metabolic cost and speed of running has been observed by Sargent (68), Furusawa (38), Knuttgen (49) and Van der Walt, et al. (73).

Sargent (68) employed an unorthodox method of determining the oxygen cost of running. He asked his subject to hold his breath over the entire running distance of 120 yards (103 metres), upon completion of which he measured the oxygen consumption until the subject reached his resting level. Using this technique, he found that the energy cost per minute increased approximately as the 3.8th power of the running speed within a speed range of 18.2 to 30.2 kilometres per hour. Furusawa, et al. (38) measured the total oxygen consumption during exercise and recovery from it for one subject running a distance of 92 metres. Within the speed range of 11.5 and 20.5 kilometres per hour, they observed a rapidly escalating curve indicating a much higher cost of running at high speeds when compared to low speeds. The investigators of both these studies justified their results by saying that at the higher speeds of running, a greater amount of active muscular effort (internal work) was required to create and destroy the momentum of the rapidly moving limbs than at the lower speeds.

Both these investigations have studied the energy cost of running short distances at moderate to high speeds. In such cases, the energy

derived from anaerobic sources is substantial (55) and increases with the speed of running. It is quite possible, therefore, that the unusually high costs observed at the higher running speeds were due to the increased utilization of the less efficient anaerobic energy source.

Knuttgen (49) suggested that the relationship between these two parameters was curvilinear when he observed the metabolic cost to increase linearly with the square of the running velocity within the speed range of 9 to 14 kilometres per hour. Between the speeds of 14 to 16.5 kilometres per hour, however, he found the rate of increase in the metabolic cost per unit increase in running velocity to decline and postulated that this was due to a retardation in the body's response to the demands of near maximal exercise.

Van der Walt and Wyndham (73) observed a curvilinear relationship between the oxygen cost and speed of running between 8 and 12.9 kilometres per hour. They derived the following equation for predicting the energy cost of running from the mass of the individual and his or her running speed.

$$\dot{V}O_2 = 0.000117MV^2 + 0.03257M - 0.419$$

where $\dot{V}O_2$ = oxygen consumption in litres per minute.

M = mass in kilograms

V = speed in kilometres per hour.

Pugh (64) has shown that the relationship between the metabolic cost and running speed depended upon the testing environment. If the

testing was done indoors on a treadmill, the relationship was linear and the energy cost could be predicted using the equation:

$$\dot{V}O_2 = 2.979S + 4.245$$

where $\dot{V}O_2$ = oxygen intake in ml/kg/min.

S = speed in kilometres per hour.

If the testing was done outdoors where the effect of wind resistance could play an important role, the relationship was curvilinear and the energy cost could be predicted using the equation:

$$\dot{V}O_2 = 0.00891V^2 + 2.853$$

where $\dot{V}O_2$ = oxygen intake in litres per minute.

V = wind velocity in metres per second.

Within the speed range of 8 kilometres per hour and 21.5 kilometres per hour, the curvilinear relationship of outdoor running that he obtained could be substituted adequately by a linear regression with a greater slope. This was given by the equation:

$$\dot{V}O_2 = 3.656S - 3.99$$

where $\dot{V}O_2$ = oxygen intake in ml/kg/min.

S = speed in kilometres per hour.

It is interesting to note that 8 out of the 9 studies reviewed that obtained linear relationships were conducted indoors while 2 out

of the 4 studies that found curvilinear relationships were done outdoors. The exceptions were Ogasawara's (60) study in the former case and Knuttgen's (49) as well as Van der Walt's and Wyndham's (73) in the latter.

Christensen and Hogberg (20) showed that the relationship between the metabolic cost and speed of running was linear between the speeds of 10 and 20 kilometres per hour if the former was calculated from the oxygen consumption under steady state conditions of exercise. The same relationship was however, found to be curvilinear if the metabolic cost was calculated from total oxygen consumption values - i.e. the oxygen consumed during the exercise as well as that which was repaid during the recovery process. This was because the ratio between the oxygen deficit and oxygen debt in their study was approximately 0.5 and not unity as has been assumed in most other studies. These researchers have, therefore, recommended the use of total oxygen consumption values in calculating the metabolic cost of any activity.

Dill (27) who observed no definite relationship between these two parameters in the case of walking was again unable to establish anything specific in the case of running. His data, however, does indicate that the metabolic cost of running increases with speed, thereby rejecting a linear relationship.

Comparison Between the Metabolic Cost of Walking and Running a Unit Distance

In 1924, Furusawa and coworkers (38) claimed that at all speeds,

the metabolic cost of walking a unit distance was greater than that of running the same distance. These researchers showed that the metabolic cost vs. speed curve for walking was consistently higher than that for running, indicating that the former was less efficicent and, therefore, required a greater number of calories to travel the same distance as the latter. In 1938, Margaria, as cited by Margaria, et al. (54) contradicted this and showed that the curves for the metabolic cost vs. speed of walking and running were non parallel and that they intersected at a point. The curvilinear plot for walking was rapidly rising and intersected the rectilinear plot for running at a speed of 8.5 kilometres per hour. This indicated that at speeds below this critical speed, walking was more efficient than running, while at speeds above the critical speed, the situation was reversed. In other words, the metabolic cost of walking a unit distance was less than that of running the same distance up to a speed of 8.5 kilometres per hour, while above this speed the metabolic cost of running a unit distance was less than that of walking the same distance. This phenomena has subsequently been observed by Boje (9), Cavagna, et al. (16), Menier and Pugh (58), Shephard (71), Van der Walt and Wyndham (73) as well as Wyndham, et al. (79). The critical speeds that these investigators observed differred to some extent and are listed in Table 2.

The critical speed of 13 kilometres per hour obtained by Cavagna, et al. (16), determined by extrapolation from Figure 3 in their article, is considerably higher than that observed by the other investigators.

Table 2 - Critical Speeds Obtained by Different Investigators

Investigators	Year	Critical Speed: Kilometres per Hour	Critical Speed: Metres per Minute
Margaria	1938	8.5	141.66
Boje	1944	8	133.33
Menier and Pugh	1968	9	150
Shephard	1969	8.9	148.33
Wyndham, et al.	1971	$>$8.1	$>$135
Van der Walt, et al.	1973	8	133.33
Cavagna, et al.	1977	13	216.66

These researchers compared the total work (sum of the internal and external work) done in walking and running a unit distance and found that up to the speed of 13 kilometres per hour, this was greater in running and therefore, the metabolic cost was also greater. A walking speed of 13 kilometres per hour is quite high and is not usually encountered in everyday life. Hence, for all practical purposes, their study indicates that running a unit distance is more expensive than walking the same distance.

Margaria, et al. (54) felt that the low economy of slow speed running compared to walking at a similar speed was probably due to the greater mechanical work performed in lifting the body to a greater height at every step. Boje (9) showed that an increase in walking speed was achieved mainly by an increase in step frequency, while an increase in running speed was the result of an increased step length. He attributed the poor economy of high speed walking to the augmented step frequency which increased the internal (muscular) work as well as to the utilization of a larger muscle mass that was characteristic of walking at these speeds. Menier and Pugh (58) felt that the low economy of fast walking as compared to running at a similar speed was because of the lesser amount of energy supplied by the elastic recoil of the skeletal muscles.

Howley and Glover (46) determined the metabolic cost of walking and running a distance of one mile using a slightly different protocol. They kept the speed of walking constant but allowed each subject to choose their 'most natural' running speed. The average walking

speed of 82 $\pm$ 3 metres per minute (4.92 $\pm$ .18 kilometres per hour) was considerably lower than the average running speed of 166 $\pm$ 14.5 metres per minute (9.96 $\pm$ .87 kilometres per hour). Under steady state measurements of oxygen consumption, they found the net metabolic cost of running to be approximately eighty percent greater than that of walking. The values calculated were 1.48 Kcal/Kg/Mile (0.93 Kcal/Kg/Km) for running compared to 0.79 Kcal/Kg/Mile (0.5 Kcal/Kg/Km) for walking. This seems to be quite consistent with Margaria's (54) claim that the energy cost of running a unit distance which is constant at 1 Kcal/Kg/Km, is twice the energy cost of walking the same distance at the most economical speed (0.5 Kcal/Kg/Km).

Sex Differences Related to the Metabolic Cost of Walking or Running a Unit Distance

In 1953 Mahadeva, et al. (53) studied the metabolic cost of walking on a sample of 35 males and 15 females from European and Asiatic countries. Using the statistical technique of multiple regression analysis they concluded that:

> "----in any physical activity in which a large proportion of energy expenditure is used to move the body weight, the metabolic cost is directly proportional to the body weight. Factors such as age, sex, surface area, race and previous dietary which are known to play an important part in determining individual basal metabolic rates, do not assume sufficient importance to add

> to the precision in assessing the cost of such activities".[1]

It is not clear from this study whether the authors are referring to the gross or net metabolic cost. Although they did measure the metabolic cost of each subject in a recumbent position, it is not stated whether this was deducted from the gross metabolic cost to obtain the net result. It, however, appears from one of the regression equations determined that the authors are referring to the gross metabolic cost.

The studies by Durnin and Namyslowski (30), Ralston (65) as well as Zarrugh, et al. (80) were also unable to detect any differences between the sexes in the gross metabolic cost of walking. Gehlsen and Dill (39) obtained similar results when they computed the net metabolic cost of grade walking. Blessey, et al. (7) were unable to find any difference in either the gross or the net metabolic cost of walking. These investigators deducted the energy cost of standing from the gross energy cost so as to obtain the net metabolic cost of walking. The energy cost of standing that they observed was approximately the same for both males and females and hence, it did not matter whether the results were expressed either as gross or net values.

Falls and Humphrey (33) were unable to detect any real difference between the sexes in the net metabolic cost of both walking and running.

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[1] Mahadeva, K., Passmore, R. and Woolf, B.; Individual Variations in the Metabolic Cost of Standardised Exercise: The Effects of Food, Age, Sex and Race.; Journal of Physiology, Vol. 121: 225-31, 1953.

Contrary to these claims, the evidence presented by Gehlsen and Dill (39) as well as Booyens and Keatinge (10) indicates that the gross energy expended by males was greater than that expended by females when walking a unit distance. Gehlsen and Dill (39) who observed no difference in the net metabolic cost of walking found that the gross metabolic cost was 3.6% higher for males than for females. They attributed this difference to the thirteen percent greater metabolic cost of standing for males that they obtained. Booyens and Keatinge (10) observed that females expended approximately ten percent less energy than males at a walking speed of 5.47 kilometres per hour. The difference in the gross energy cost had a tendency to increase as the speed of walking increased. The explanation offered by these authors was as follows. The 'more forward' acetabular fossae as well as slightly shorter ilio-femoral ligaments of the females restricted the extension of their hip joints while walking. This resulted in the females having significantly shorter stride lengths than the males. Consequently, the females did a significantly lesser amount of work against gravity resulting in a lower energy expenditure. As the speed of walking increased, the difference in stride length between the sexes also increased thereby increasing the difference in vertical work done,and therefore the energy cost of walking. Falls and Humphrey (33) who observed no real difference between males and females in this regard felt that this explanation was insufficient and argued that if the distance to be walked was the same, then a shorter stride length of the females would inevitably be accompanied by a greater step frequency on their

part. Increasing the step frequency would result in a greater amount of energy being expended due to internal work and therefore, offset some of the energy conserved due to the decreased lift work. Hence, the difference in energy expenditure between males and females would be almost negligible. These investigators, however, admitted that they could not utilize the same argument for the insignificant differences that they obtained in the case of running. Even though running stride lengths were greater in males than in females, this did not result in an increase in lift work. On the contrary, the lift work calculated per unit distance run actually decreased which seems to confirm the findings of Cavagna, et al. (17). The decreased lift work of the males coupled with their lower step frequency would probably result in a lower energy expenditure on their behalf and contradict their findings that the difference between males and females in the metabolic cost of running was insignificant.

McDonald (57) collated the data of all the studies done on the metabolic cost of walking between the years 1912 to 1958. He found that on the average, the gross metabolic cost of walking a unit distance was ten to twelve percent higher in males than in females.

Howley and Glover (46) as well as Bransford and Howley (12) have presented a third opinion by showing that the metabolic cost of walking and running a unit distance was greater in females than in males. Howley and Glover (46) found that both the gross and net metabolic costs of walking and running were significantly greater in females than in males with the difference being more accentuated while

running. They felt that the higher metabolic cost of running of the females was probably due to their slower running speed, 137 metres per minute vs. 195 metres per minute for males, which resulted in more lift work being done. Bransford and Howley (12) computed only the gross metabolic cost of running and found it to be significantly higher in females than in males. In this study both sexes ran at similar speeds, but once again the authors felt that the higher energy cost of the women was apparently due to a greater vertical displacement of their bodies.

Durnin (29) in an article titled "Sex differences in energy intake and expenditure" claimed that if the energy cost of any activity was calculated per unit of gross body weight, then males expended more energy than females, but if it was calculated per unit of lean body mass then there was no difference whatsoever. The concept of lean body mass, however, was physiologically an unacceptable unit of reference and hence, for all practical purposes the metabolic cost of any activity, according to them, was significantly greater for males than for females.

CHAPTER 3

METHODS AND PROCEDURES

Subjects

A total of 24 subjects, 12 females and 12 males, volunteered to take part in this study. Fourteen of these subjects, 8 females and 6 males, were students attending physical education classes at the University of Alberta. The remaining 10 subjects, 4 females and 6 males, were active members of the Royal Glenora Club in Edmonton. All these subjects participated in one or more of the following activities either on a recreational or competitive basis: tennis, badminton, squash, racquetball, basketball, swimming and jogging. Each subject was capable of walking and running a distance of one kilometre without encountering any physical problems.

Anthropometrical Data

The following anthropometrical data, the means of which are given in Table 3, was collected from each subject: age in months, height in centimetres, leg length in centimetres measured as the vertical distance from the right anterior spine of the iliac crest to the floor and mass in kilograms. These measurements were taken with the subject wearing gym strip and flat heeled running shoes. The mass in kilograms of each subject when wearing only a swimsuit was also measured while determing percent body fat. Also given in Table 3 is the mean predicted maximum oxygen uptake of both the groups of subjects. The individual values for all the above measurements are available in Tables 46 and 47, Appendix E.

Table 3 - Characteristics of Female and Male Subjects

Sex (n=12)	Age (months)	Height (cms)	Leg Length (cms)	Height / Leg Length	Mass (kgs) 1*	Mass (kgs) 2**	Percent Fat	Predicted VO_2 ml/kg/min.
Female	251	166.68	104.70	1.598	57.96	56.69	17.35	51.76
Male	284.5	175.50	106.88	1.642	70.46	69.03	9.54	56.12

*Mean mass at time of test walk and test run (sessions 3 and 4) - subject wearing gym strip and running shoes.

**Mass measured at the time of determination of percent body fat (session 1).

The Beckman Metabolic Measurement Cart (MMC)

This system has been designed to facilitate rapid assessment of respiratory and metabolic parameters both at rest and during exercise. Briefly, the MMC consists of two major components:

1) A set of analyzers or sensors for measuring oxygen, carbon dioxide, expired air volume, expired air temperature, barometric pressure and time.

2) A programmable calculator which oversees the operation of the measurement cycles, performs all the required calculations and prints the calculated data.

Further details regarding this system are available in the article by Wilmore, et al. (75).

Calibration of the Beckman Metabolic Measurement Cart

At the beginning of each testing session that this system was going to be used, it was calibrated for volume, partial pressures of oxygen and carbon dioxide, barometric pressure and temperature according to standards laid down in the manual supplied with the instrument so as to ensure accurate measurements.

Prior to each measurement on a subject, the system was calibrated using a mixture of 17.95% oxygen and 3.23% carbon dioxide calibration gas. However, in some cases, due to the non availability of the calibration gas, the system was calibrated using atmospheric air assuming a value of 20.93% for oxygen and 0.03% for carbon dioxide. Following each measurement on a subject, the system was recalibrated to check for the reliability of the measurements.

Testing Procedure

Testing was carried out over a period of 8 weeks during which each subject attended four testing sessions.

Session 1

a) Prediction of Maximal Oxygen Uptake

This test was carried out in order to define the sample of subjects being tested more accurately. The submaximal bicycle test suggested by Astrand and Rhyming (5) was used for this purpose. The procedure followed was exactly as outlined by these authors and the maximal oxygen uptake values obtained from the nomogram were corrected for age as suggested by Astrand, I. (3).

b) Estimation of Percent Body Fat

The percentage of body fat on each subject was estimated using the underwater weighing technique described by Sloan (72) and the body density formula derived by Brozek, et al. (14).

Session 2

Determination of the Optimal Speeds of Walking and Running.

The purpose of this session was threefold: (a) to familiarize the subjects with walking and running on a treadmill (b) to determine the optimal speed of walking and (c) to determine the optimal speed of running.

The optimal speed of walking was determined in the following manner. As a precautionary measure, the subject was 'hooked up' to a set of electrodes and cardiotachometer (Cardionics AB, Stockholm) so that the heart rate could be monitored throughout the testing session. The motor

driven treadmill was started at its slowest speed. The subject stepped on to the treadmill and under his or her guidance, the speed was gradually increased until one which he or she felt was most comfortable was attained. The treadmill speed was then increased and decreased several times above and below this speed to ensure that the speed selected was in fact the most comfortable speed. In cases where the subject was uncertain, then the lower speed was chosen as the most comfortable speed. The treadmill was then brought to a halt and the time that the treadmill belt would take to travel a distance of 1 kilometre was calculated from the speed selected. The treadmill was started once again at this speed and the subject was allowed to walk the distance of 1 kilometre. At regular intervals during the walk, the subject was asked if the speed that he or she was walking at was most comfortable. Any modifications that had to be made were done during this period.

After allowing the subjects to rest for thirty minutes, the optimal speed of running was determined in exactly the same manner.

A day before the third testing session began, each subject was given written instructions (Appendix B) to avoid physical activity and ingestion of foods and nutrients for at least 2 hours prior to the time they were supposed to be tested in sessions 3 and 4.

<u>Session 3</u>

<u>a) Determination of the Energy Cost of Standing.</u>

This was determined so that by deducting its value from the gross energy cost of walking, the net energy cost of walking could be calculated.

The energy cost of standing was determined as follows. The subject

rested for a period of thirty minutes after entering the testing laboratory following which he or she stood 'at ease' on the treadmill. The subjects heart rate was monitored using the cardiotachometer and his or her oxygen consumption while standing 'at ease' was determined for a period of six minutes with the help of the MMC. The average value of oxygen consumed per minute for the last five minutes of standing was calculated as the energy cost of standing. Figure 4 shows the subject in the appropriate testing position.

b) Determination of the Energy Cost of Walking.

The arrangements for monitoring the heart rate and determining the energy cost were maintained as before. The treadmill speed was adjusted to the subject's previously determined optimal speed of walking. The subject then stepped on to the treadmill and began walking at its speed. The metabolic cart was started simultaneously so that the oxygen consumption could be measured for as long as desired. After the treadmill belt had travelled a distance of one kilometre (time taken to accomplish this was calculated in Session 2) it was stopped. The subject then stood 'at ease' on the treadmill and the oxygen consumption was measured until it reached the average standing level determined prior to the walk. The total volume of oxygen consumed during the walk and the recovery period was used to calculate the energy cost of walking.

The vertical lift of the body was determined in the following manner.

Figure 4 - Subject in the Appropriate Standing Position

A 16mm movie camera (Photosonics, Inc.; Burbank, California, U.S.A.) was placed at a distance of 5 metres from the rear end of the treadmill so that it was focussed on the subjects entire back. The camera, loaded with Kodak Eastman Ektachrome 7239 film, was set at a speed of 50 frames per second and a shutter angle of 160^{o} resulting in an exposure time of 1/110 second. An electrode was placed on the subjects spinal column at the level of the fifth lumbar vertebra to serve as a point of reference. Filming was done at two stages - after the subject had completed 25% and 75% of the distance walked (¼ kilometre and 3/4 kilometre respectively), and on each occasion 3 strides were filmed. The film was subsequently analyzed using a Hewlett Packard 9825 A computer to measure the vertical displacement of the electrode for each step. The average of the six vertical displacements was assumed to be the vertical lift per step.

The step frequency was counted manually for 2 minutes during the middle of the walk. From this value the step frequency per kilometre of distance walked was calculated.

Session 4

The energy costs of standing and running, as well as the vertical lift per step and step frequency per kilometre of distance run were determined in exactly the same manner as described for the walk in session 3.

Determination of the Energy Cost from Values of Oxygen Consumption.

The values of oxygen consumption obtained were converted into energy equivalents in the following manner. First, from each 30 second Beckman

computer printout the volume of oxygen consumed as well as the R.Q. was noted. Second, this R.Q. value was used to determine the Kilocaloric equivalent of one litre of oxygen from Carpenter's tables (15). Third, the volume of oxygen consumption was multiplied by the Kilocaloric equivalent to obtain the energy cost.

Experimental Design.

Each one of the 12 female and 12 male subjects was randomly assigned a number between 1 and 12. All four testing sessions were carried out with the subjects being tested in serial order. Sessions 3 and 4, however, were modified in the following manner. Subjects with odd numbers, starting with number 1, did the walking test first (session 3) while those with even numbers starting with number 2, did the running test first (session 4). Once all the subjects in a group had completed one test, only then were they allowed to do the remaining test, but this time the order of testing was reversed. The experimental design was similar for both females and males except in one instance. Male subject number 12 who originally volunteered for the study had to be replaced after the first two sessions due to injury. His replacement completed the 4 testing sessions in 2 days only after all the other subjects had completed their testing. This subject did the tests in the same order that the original subject was scheduled to do them - session 1, session 2, session 4 (test run) and session 3 (test walk).

Validation of the Measurement of the Vertical Lift of the Body

Strictly speaking, the vertical lift of the body should have been determined by measuring the vertical displacement of the center of gravity. The cinematographic technique for tracing the path of the center

of gravity required the camera to be set up at right angles to the subject. Due to the lack of space in the testing laboratory to set up the camera in this position, filming was done from the back and the vertical lift of the body was determined by the method already described. The degree of error between this measurement and the true vertical lift of the body was estimated in the following manner.

Two cameras, one placed at right angles to the subject and the other placed behind him, were set up in an open gymnasium at a frame rate of 25 frames per second, a shutter angle of 160^{o} and at a distance of 5 metres from the subject. The 2 cameras were synchronized so that they could be started and stopped simultaneously. The subject, with an electrode placed on his spinal column at the level of the fifth lumbar vertebra (just as before), walked at his optimal speed in a linear direction across the gymnasium. The 2 cameras were started simultaneously and the subject was filmed for 3 strides. The 2 films were analyzed to measure the vertical displacements of the center of gravity and the electrode placed on the spinal column. The degree of error was calculated as the difference between the means of the vertical displacement of the electrode and the vertical displacement of the center of gravity, expressed as a percentage. Two of the subjects who had volunteered for this study, one female and one male, were used for this validation procedure. Both these subjects were filmed while walking and running at their optimal speeds.

Statistical Analysis

The data collected was subjected to a two way analysis of variance with repeated measures on one factor (76) for each of the following

variables: (1) standing energy cost (2) optimal speed (3) step frequency (4) step length (5) vertical lift per step (6) vertical lift per kilometre (7) oxygen consumption during exercise (8) recovery time (9) oxygen consumption during recovery (10) total time (11) total oxygen consumption (12) gross energy cost per kilometre (13) standing energy cost for the total time of the activity (14) net energy cost per kilometre (15) gross energy cost per step and (16) net energy cost per step. The 'F' ratios that were significant at the .05 level of confidence (α =.05) were then subjected to the appropriate 't' test to find out the exact location of these differences. Since the number of groups in this study was only 2, a more sophisticated technique for multiple comparisons was not used.

CHAPTER 4

RESULTS AND DISCUSSION

Analysis of Results

Energy cost of standing.

Table 4 shows the mean energy cost per minute of standing prior to walking and running in the female and male subjects. The analysis of variance with repeated measures on the energy cost of standing (Table 5) revealed that:

(a) There was no significant difference in the energy cost of standing prior to walking and running in females and males ($P = .780$).

(b) There was no significant difference between females and males in the energy cost of standing prior to both walking and running ($P = .272$).

Table 6 shows the means of the optimal speed, exercise (walking or running) time, step frequency, step length, vertical lift per step and vertical lift per kilometre of walking and running in the female and male subjects. The results of the analysis of variance with repeated measures on one factor and those of the 't' test, where necessary, were as follows.

Optimal speed of walking and running (Tables 7, 8).

a) The optimal speed of running was significantly higher than that of walking in both females and males ($P < .001$ in both cases).

b) There was no significant difference between females and males in the optimal speed of walking ($P = .058$). The optimal speed of running how-

Table 4 - The Mean Energy Cost of Standing prior to Walking and Running in Females and Males

Sex (n=12)	Activity	Standing Oxygen Consumption		R.Q.	Standing Energy Cost	
		ml/min.	ml/kg/min.		Kcals/min.	Kcals/kg/min.
Female	Walking	229.2	3.98	0.79	1.0978	0.0190
	Running	240.1	4.13	0.79	1.1488	0.0198
Male	Walking	303.6	4.32	0.81	1.4642	0.0208
	Running	293.33	4.18	0.80	1.4106	0.0202

Table 5 - Summary of Analysis of Variance

Standing Energy Cost

Source of Variation	SS	DF	MS	'F'	P
Between subjects	0.000	23			
'A' Main effects	0.000	1	0.000	1.271	0.272
Subjects within groups	0.000	22	0.000		
Within subjects	0.000	24			
'B' Main effects	0.000	1	0.000	0.080	0.780
AB interaction	0.000	1	0.000	0.903	0.352
B x subjects within groups	0.000	22	0.000		

Table 6 - Characteristics of the Mean Optimal Walking and Running Speeds in Females and Males

Sex	Activity	Optimal Speed		Time to travel 1 Km. (mins:secs)	Step Frequency (steps/km)	Step Length (cms/step)	Vertical Lift	
		kmh	metres/min.				Lift/step (cms)	Lift/km. (cms)
Female	Walking	4.6398	77.33	13:00	1442.66	69.62	3.15	4507.39
	Running	8.6211	143.69	6:58	1097.83	91.60	8.89	9717.90
Male	Walking	4.8913	81.46	12.21	1350.66	74.43	3.31	4442.93
	Running	9.2936	154.89	6:30	1025.91	96.71	8.80	9087.17

Table 7 - Summary of Analysis of Variance

Optimal Speed

Source of Variation	SS	DF	MS	'F'	P
Between subjects	2737.875	23			
'A' Main effects	711.938	1	711.938	7.733	0.011
Subjects within groups	2025.438	22	92.065		
Within subjects	59676.250	24			
'B' Main effects	58569.949	1	58569.949	1344.679	$<.001$
AB interaction	148.172	1	148.172	3.402	0.079
B x subjects within groups	958.250	22	43.557		

Table 8 - 't' Test Results

Comparison	Sex	't'	P	Comparison	Activity	't'	P
Walking vs. Running	Female	36.208	$<.001$	Female vs. Male	Walking	-1.639*	0.058
Walking vs. Running	Male	21.972	$<.001$	Female vs. Male	Running	-2.797*	0.005

* - sign indicates slower speed for females.

ever was significantly higher in males than in females ($P = .005$).

Step frequency (Tables 9, 10).

a) For both females and males, running step frequencies were significantly less than walking step frequencies ($P < .001$ in each case).

b) The step frequency of walking was significantly higher in females than in males ($P = .019$). The running step frequency was not significantly different between the two groups ($P = .096$).

Step Length (Tables 11, 12).

a) The running step lengths were significantly longer than the walking step lengths in both groups of subjects ($P < .001$ in each case).

b) Males had a significantly longer walking step length than the females ($P = .017$). There was no significant difference in the running step length between the two groups ($P = .072$).

Vertical lift per step (Tables 13, 14).

a) The vertical lift per running step was significantly higher than the vertical lift per walking step in both groups of subjects ($P < .001$ in both cases).

b) The differences between females and males in the vertical lift per walking and running step were insignificant ($P = .926$).

Vertical lift per kilometre (Tables 15, 16).

a) In both females and males, the vertical lift per kilometre of distance run was significantly greater than the vertical lift per kilometre of distance walked ($P < .001$ in each case).

b) There was no significant difference between females and males in the vertical lift per kilometre of walking or running ($P = 0.280$).

Table 17 indicates the means of the volume of oxygen consumed during

Table 9 - Summary of Analysis of Variance

Step Frequency

Source of Variation	SS	DF	MS	'F'	P
Between subjects	371712	23			
'A' Main effects	60840	1	60840	4.304	0.049
Subjects within groups	310960	22	14135		
Within subjects	1366330	24			
'B' Main effects	1258420	1	1258420	269.791	$<.001$
AB interaction	5300	1	5300	1.137	0.298
B x subjects within groups	102620	22	4660		

Table 10 - 't' Test Results

Comparison	Sex	't'	P	Comparison	Activity	't'	P
Walking vs. Running	Female	16.590	$<.001$	Female vs. Male	Walking	2.212	0.019
Walking vs. Running	Male	9.048	$<.001$	Female vs. Male	Running	1.343	0.096

Table 11 - Summary of Analysis of Variance

Step Length

Source of Variation	SS	DF	MS	'F'	P
Between subjects	1771.313	23			
'A' Main effects	290.766	1	290.766	4.32	0.049
Subjects within groups	1480.750	22	67.307		
Within subjects	6508.688	24			
'B' Main effects	5899.641	1	5899.641	213.167	<.001
AB interaction	0.188	1	0.188	0.007	0.935
B x subjects within groups	608.875	22	27.676		

Table 12 - 't' Test Results

Comparison	Sex	't'		Comparison	Activity	't'	P
Walking vs. Running	Female	15.118	<.001	Female vs. Male	Walking	-2.254*	0.017
Walking vs. Running	Male	8.387	<.001	Female vs. Male	Running	-1.513*	0.072

* - sign indicates shorter step length for female subjects.

Table 13 - Summary of Analysis of Variance

Vertical Lift per Step

Source of Variation	SS	DF	MS	'F'	P
Between subjects	30.748	23			
'A' Main effects	0.012	1	0.012	0.009	0.926
Subjects within groups	30.735	22	1.397		
Within subjects	397.146	24			
'B' Main effects	378.281	1	378.281	445.566	$<.001$
AB interaction	0.189	1	0.189	0.222	0.642
B x subjects within groups	18.678	22	0.849		

Table 14 - 't' Test Results

Comparison	Sex	't'	P
Walking vs. Running	Female	13.950	$<.001$
Walking vs. Running	Male	16.279	$<.001$

Table 15 - Summary of Analysis of Variance

Vertical Lift per Kilometre

Source of Variation	SS	DF	MS	'F'	P
Between subjects	26339380	23			
'A' Main effects	1358440	1	1358440	1.196	0.286
Subjects within groups	24983130	22	1135600		
Within subjects	311187500	24			
'B' Main effects	294561600	1	294561600	409.630	< .001
AB interaction	806720	1	806720	1.122	0.301
B x subjects within groups	15820000	22	719090		

Table 16 - 't' Test Results

Comparison	Sex	't'	P
Walking vs. Running	Female	11.935	< .001
Walking vs. Running	Male	21.245	< .001

Table 17 - The Mean Gross Energy Cost of Walking and Running One Kilometre in Females and Males.

Sex (n=12)	Activity	Speed kmh	Total Time		Total Oxygen Consumption				R.Q.	Gross Energy Cost	
			Exercise mins:secs	Recovery mins:secs	Exercise ml	Exercise ml/kg	Recovery ml	Recovery ml/kg		Kcals/Km.	Kcals/Kg/Km.
Female	Walking	4.6398	13:00	2:40	9005	155.6	840	14.4	0.83	47.6324	0.8224
	Running	8.6211	6:58	6:49	12459	214.7	3093	53.9	0.91	76.5611	1.3221
Male	Walking	4.8913	12:21	2:14	10616	151.2	864	12.1	0.86	55.9893	0.7948
	Running	9.2936	6:30	5:33	13664	194.7	2932	40.7	0.91	79.1252	1.1596

exercise, recovery time from exercise, volume of oxygen consumed during the recovery period and the gross energy cost of walking and running in the female and male subjects. The results of the statistical analysis on each of these variables were as follows.

<u>Oxygen consumption during exercise (Tables 18, 19)</u>.

a) In both females and males, the oxygen consumed during the run was significantly greater than that consumed during the walk ($P < .001$ for both groups).

b) There was no significant difference between females and males in the oxygen consumed during the walk ($P = .241$). The oxygen consumed during the run, however, was significantly greater in the females than in the males ($P = .029$).

<u>Recovery time from exercise (Tables 20, 21)</u>.

a) The time taken to recover from the run was significantly longer than that taken to recover from the walk in both the groups of subjects ($P = .001$ and $P = .002$ for females and males respectively).

b) Females and males did not exhibit any significant differences in the time taken to recover from either the run or the walk ($P = .194$).

<u>Oxygen consumption during the recovery period (Tables 22, 23)</u>.

a) For both groups of subjects the oxygen consumption during the recovery period from running was significantly higher than that during the recovery period from walking ($P < .001$ in both cases).

b) No significant differences between the sexes were observed in the oxygen consumed during the recovery period from either walking or running ($P = .088$).

Table 18 - Summary of Analysis of Variance

Exercise Oxygen Consumption

Source of Variation	SS	DF	MS	'F'	P
Between subjects	1.061	23			
'A' Main effects	0.178	1	0.178	4.424	0.047
Subjects within groups	0.883	22	0.040		
Within subjects	4.148	24			
'B' Main effects	3.155	1	3.155	75.339	<.001
AB interaction	0.072	1	0.072	1.726	0.202
B x subjects within groups	0.921	22	0.042		

Table 19 - 't' Test Results

Comparison	Sex	't'	P	Comparison	Activity	't'	P
Walking vs. Running	Female	7.838	<.001	Female vs. Male	Walking	0.715	0.241
Walking vs. Running	Male	4.781	0.001	Female vs. Male	Running	2.006	0.029

Table 20 - Summary of Analysis of Variance

Recovery Time

Source of Variation	SS	DF	MS	'F"	P
Between subjects	418590	23			
'A' Main effects	31623	1	31623	1.798	0.194
Subjects within groups	386969	22	17589		
Within subjects	967792	24			
'B' Main effects	602115	1	602115	36.973	$<.001$
AB interaction	7398	1	7398	0.454	0.507
B x subjects within groups	358280	22	16285		

Table 21 - 't' Test Results

Comparison	Sex	't'	P
Walking vs. Running	Female	4.496	0.001
Walking vs. Running	Male	4.095	0.002

Table 22 - Summary of Analysis of Variance

Recovery Oxygen Consumption

Source of Variation	SS	DF	MS	'F'	P
Between subjects	5407.156	23			
'A' Main effects	684.000	1	684.000	3.186	0.088
Subjects within groups	4723.121	22	214.687		
Within subjects	18660.781	24			
'B' Main effects	14042.438	1	14042.438	72.196	$<.001$
AB interaction	339.281	1	339.281	1.744	0.200
B x subjects within groups	4279.082	22	194.504		

Table 23 - 't' Test Results

Comparison	Sex	't'	P
Walking vs. Running	Female	10.528	$<.001$
Walking vs. Running	Male	7.412	$<.001$

Total time for measurement of oxygen consumption, given by the sum of the exercise and recovery times (Tables 24, 25).

a) The total time for which oxygen consumption was measured was not significantly different between walking and running in females ($P = .066$). In males, however, the difference was significant, with the total time being longer for walking than for running ($P = .012$).

b) The females had a significantly longer total time for which oxygen consumption was measured than the males only for the walk ($P = .024$). No significant difference between the sexes was observed for running ($P = .074$).

Total oxygen consumption (Tables 26, 27).

a) The total oxygen consumed during the exercise and recovery periods of running was significantly higher than that of walking in both the groups of subjects ($P < .001$ in each case).

b) The females and males did not exhibit any significant differences in the total oxygen consumed during the exercise and recovery periods of walking ($P = .161$). The total oxygen consumption of running, however, was significantly higher in the females ($P = .024$).

Gross energy cost per kilometre (Tables 28, 29).

a) The gross energy cost of running was significantly greater than the gross energy cost of walking for both the groups of subjects ($P < .001$ in each case).

b) Females and males did not exhibit any significant difference in the gross energy cost of walking ($P = .187$). The gross energy cost of running, however, was greater in females than in males ($P = .023$).

The net energy cost per kilometre was calculated by deducting the

Table 24 - Summary of Analysis of Variance

Total Time

Source of Variation	SS	DF	MS	'F'	P
Between subjects	135.980	23			
'A' Main effects	24.082	1	24.082	4.735	0.041
Subjects within groups	111.898	22	5.086		
Within subjects	163.000	24			
'B' Main effects	58.521	1	58.521	12.482	0.002
AB interaction	1.339	1	1.339	0.286	0.598
B x subjects within groups	103.148	22	4.689		

Table 25 - 't' Test Results

Comparison	Sex	't'	P	Comparison	Activity	't'	P
Walking vs. Running	Female	2.044	0.066	Female vs. Male	Walking	2.087	0.024
Walking vs. Running	Male	2.992	0.012	Female vs. Male	Running	1.501	0.074

Table 26 - Summary of Analysis of Variance

Total Oxygen Consumption

Source of Variation	SS	DF	MS	'F'	P
Between subjects	2.542	23			
'A' Main effects	0.465	1	0.465	4.928	0.037
Subjects within groups	2.077	22	0.094		
Within subjects	10.710	24			
'B' Main effects	8.763	1	8.763	110.587	$<.001$
AB interaction	0.204	1	0.204	2.574	0.123
B x subjects within groups	1.743	22	0.079		

Table 27 - 't' Test Results

Comparison	Sex	't'	P	Comparison	Activity	't'	P
Walking vs. Running	Female	7.102	$<.001$	Female vs. Male	Walking	1.015	0.161
Walking vs. Running	Male	8.551	$<.001$	Female vs. Male	Running	2.085	0.024

Table 28 - Summary of Analysis of Variance

Gross Energy Cost per Kilometre

Source of Variation	SS	DF	MS	'F'	P
Between subjects	0.605	23			
'A' Main effects	0.108	1	0.108	4.795	0.039
Subjects within groups	0.497	22	0.023		
Within subjects	2.2694	24			
'B' Main effects	2.242	1	2.242	123.988	$<.001$
AB interaction	0.055	1	0.055	3.019	0.096
B x subjects within groups	0.398	22	0.018		

Table 29 - 't' Test Results

Comparison	Sex	't'	P	Comparison	Activity	't'	P
Walking vs. Running	Female	7.276	$<.001$	Female vs. Male	Walking	0.906	0.187
Walking vs. Running	Male	10.077	$<.001$	Female vs. Male	Running	2.123	0.023

energy cost of standing for the total time for which oxygen consumption was measured for the activity from its gross energy cost. Table 30 indicates the mean values of the above variables in both the groups of subjects while walking and running. The results of the statistical analysis carried out on the energy cost of standing for the total duration of the activity and the net energy cost were as follows.

Standing energy cost for the total time of the activity (Tables 31, 32).

a) In females, there was no significant difference between walking and running in the energy cost of standing for the total time of the activity ($P = .280$). In males however, the energy cost of standing for the total duration of the walk was significantly higher than that for the run ($P = .032$).

b) There was no significant difference between females and males in the energy cost of standing for the total duration of either the walk or the run ($P = .511$).

Net energy cost per kilometre (Tables 33, 34).

a) For both the groups of subjects, the net energy cost of running was significantly higher than that of walking ($P < .001$ in each case).

b) There was no significant difference between the sexes in the net energy cost of walking ($P = 0.144$). The net energy cost of running, however, was significantly higher in females than in males ($P = .022$).

The energy cost per step was calculated by dividing the energy cost per kilometre and the step frequency per kilometre of each activity. Table 35 indicates the gross and net energy costs per step of walking and running in the females and males. The results of the statistical analysis on these two variables were as follows.

Table 30 - The Mean Net Energy Cost of Walking and Running One Kilometre in Females and Males.

Sex (n=12)	Activity	Total Time (mins:secs)	Gross Energy Cost Kcals/Kg/Km.	Standing Energy Cost		Net[2] Energy Cost Kcals/Kg/Km.
				Kcals/Kg/min.	Kcals/Kg/Km.[1]	
Female	Walking	15:40	0.8224	0.0190	0.2966	0.5258
	Running	13:47	1.3221	0.0198	0.2716	1.0505
Male	Walking	14:35	0.7948	0.0208	0.3017	0.4931
	Running	12:03	1.1596	.0202	0.2452	0.9233

[1]Standing Energy Cost, Kcals/Kg/Km. = Total Time x Standing Energy Cost, Kcals/Kg/min.

[2]Net Energy Cost = Gross Energy Cost - Standing Energy Cost, Kcals/Kg/Km.

Table 31 - Summary of Analysis of Variance

Standing Energy Cost for Total Time

Source of Variation	SS	DF	MS	'F'	P
Between subjects	0.064	23			
'A' Main effects	0.001	1	0.001	0.446	0.511
Subjects within groups	0.062	22	0.003		
Within subjects	0.089	24			
'B' Main effects	0.020	1	0.020	6.573	0.018
AB Interaction	0.003	1	0.003	1.022	0.323
B x subjects within groups	0.066	22	0.003		

Table 32 - 't' Test Results

Comparison	Sex	't'	P
Walking vs. Running	Female	1.135	0.280
Walking vs. Running	Male	2.449	0.032

Table 33 - Summary of Analysis of Variance

Net Energy Cost per Kilometre

Source of Variation	SS	DF	MS	'F'	P
Between subjects	0.403	23			
'A' Main effects	0.077	1	0.077	5.173	0.033
Subjects within groups	0.327	22	0.015		
Within subjects	3.024	24			
'B' Main effects	2.735	1	2.735	229.868	<.001
AB interaction	0.027	1	0.027	2.248	0.148
B x subjects within groups	0.262	22	0.012		

Table 34 - 't' Test Results

Comparison	Sex	't'	P	Comparison	Activity	't'	P
Walking vs. Running	Female	9.954	<.001	Female vs. Male	Walking	1.091	0.144
Walking vs. Running	Male	12.480	<.001	Female vs. Male	Running	2.134	0.022

Table 35 - The Mean Gross and Net Energy Cost per Step of Walking and Running in Females and Males

Sex (n=12)	Activity	Step Frequency	Gross Energy Cost		Net Energy Cost	
			Kcals/Kg/Km.	cals[1]/Kg/step[2]	Kcals/Kg/Km.	cals[1]/Kg/step[3]
Female	Walking	1442.66	0.8224	0.5707	0.5258	0.3654
	Running	1097.83	1.3221	1.2117	1.0505	0.9638
Male	Walking	1350.66	0.7948	0.5938	0.4931	0.3673
	Running	1025.91	1.1596	1.1267	0.9233	0.8968

[1] 1 gram calorie (abbreviated as cals) is equivalent to .001 Kilocalorie.

[2] Gross Energy Cost, cals/Kg/step, is given by $\frac{\text{Gross Energy Cost (Kcals/Kg/Km)} \times 1000}{\text{Step Frequency (steps/Km)}}$

[3] Net Energy Cost, cals/Kg/step, is given by $\frac{\text{Net Energy Cost (Kcals/Kg/Km)} \times 1000}{\text{Step Frequency Cost (steps/Km)}}$

Gross energy cost per step (Tables 36,37).

a) In both sexes, the gross energy cost per step of running was significantly greater than that of walking ($P < .001$ in each case).

b) There was no significant difference between the sexes in the gross energy cost per step of either walking or running ($P = .507$).

Net energy cost per step. (Tables 38, 39).

a) The net energy cost per running step was significantly greater than that of a walking step in both the groups of subjects ($P < .001$ in each case).

b) No sex differences were observed in the net energy cost per step of either walking or running ($P = .417$).

Validity of the measurement of the vertical lift of the body.

The results of the experiment carried out to validate the measurement of the vertical lift of the body are given in table 40. In both sexes, the vertical lift per step of walking and running determined by the method used in this study was higher than the vertical displacement per step of the centre of gravity of the body. The degree of error for walking was 4.47% and 4.44% in females and males respectively, the mean error being 4.46%. For running the degree of error was slightly higher. The values for females and males were 6.66% and 5.35% respectively with the mean error being 6%.

Discussion

The Energy Cost of Standing

Table 4 showed the mean energy cost of standing prior to walking and running in the female and male subjects. The individual values are given

Table 36 - Summary of Analysis of Variance

Gross Energy Cost per Step

Source of Variation	SS	DF	MS	'F'	P
Between subjects	0.623	23			
'A' Main effects	0.013	1	0.013	0.455	0.507
Subjects within groups	0.610	22	0.028		
Within subjects	4.639	24			
'B' Main effects	4.155	1	4.155	202.676	$<.001$
AB interaction	0.033	1	0.033	1.620	0.216
B x subjects within groups					

Table 37 - 't' Test Results

Comparison	Sex	't'	P
Walking vs. Running	Female	7.644	$<.001$
Walking vs. Running	Male	10.924	$<.001$

Table 38 - Summary of Analysis of Variance

Net Energy Cost per Step

Source of Variation	SS	DF	MS	'F'	P
Between subjects	0.421	23			
'A' Main effects	0.013	1	0.013	0.683	0.417
Subjects within groups	0.408	22	0.019		
Within subjects	4.137	24			
'B' Main effects	3.816	1	3.816	273.469	$<.001$
AB interaction	0.014	1	0.014	1.023	0.323
B x subjects within groups	0.307	22	0.014		

Table 39 - 't' Test Results

Comparison	Sex	't'	P
Walking vs. Running	Female	11.251	$<.001$
Walking vs. Running	Male	12.406	$<.001$

Table 40 - Validity of the Measurement of the Vertical Lift of the Body

Subject Number	Sex	Activity	Mean Vertical Lift (cms)		Percentage Error
			Reference Point	Centre of Gravity	
1	Female	Walking	3.27	3.13	4.47
2	Male	Walking	2.82	2.70	4.44
					Mean=4.46
1	Female	Running	9.12	8.55	6.66
2	Male	Running	8.08	7.67	5.35
					Mean=6.00

in Tables 48 and 49, Appendix F. In females, prior to walking, the range was from 0.0146 Kcals/kg/min. to 0.0246 Kcals/kg/min. with the mean being 0.0190 Kcals/kg/min. (S.D.$\pm$ 0.0019 Kcals/kg/min.), while prior to running, the range was from 0.0144 Kcals/kg/min. to 0.0238 Kcals/kg/min. with the mean being 0.0198 Kcals/kg/min. (S.D.$\pm$ 0.0016 Kcals/kg/min.). In males, prior to walking, the range was from 0.0168 Kcals/kg/min. to 0.0268 Kcals/kg/min. with the mean being 0.0208 Kcals/kg/min. (S.D.$\pm$ 0.0018 Kcals/kg/min.) while prior to running, the range was from 0.0149 Kcals/kg/min. to 0.0254 Kcals/kg/min. with the mean being 0.0202 Kcals/kg/min (S.D.$\pm$ 0.0023 Kcals/kg/min.). The statistical analysis indicated that in both the groups of subjects there was no significant difference in the energy cost of standing prior to the two activities. As well, the differences between females and males in the energy cost of standing prior to each activity were insignificant.

It is evident from the individual values that there was no consistency in the energy cost of standing from one session to another. For example, female subject number 11 had a value of 0.0199 Kcals/kg/min. prior to walking and a value of 0.0230 Kcals/kg/min. prior to running - an increase of 19.6%. On the other hand, male subject number 6 had a value of 0.0230 Kcals/kg/min. prior to walking and a value of 0.0165 Kcals/kg/min. prior to running - a decrease of 28.26%. The inter-individual and intra-individual differences in the energy cost of standing could have been due to differences in (a) activity levels prior to testing (b) ingestion of foods and nutrients prior to testing (c) the time of day at which testing was carried out (d) standing posture (e) anticipation of exercise and possibly (f) training level of the subjects.

Although the subjects in this study were given written instructions to avoid physical activity and ingestion of foods and nutrients for at least two hours before testing, this was not rigidly controlled. A certain amount of control was attained by imposing a half hour resting period before the commencement of actual testing. The time of day at which the testing was carried out varied among individuals and it was not controlled in any manner. While determining the energy cost of standing the subjects were asked to stand at 'ease' with their hands by their sides and they maintained this posture as best they could.

In this study, the combined mean energy cost of standing prior to walking and running was 0.0194 Kcals/kg/min. for females and 0.0205 Kcals/kg/min. for males. These values are lower than those reported by Katch and McArdle (48) as well as Gehlsen and Dill (39). These authors reported values of 0.025 Kcals/kg/min., 0.027 Kcals/kg/min., 0.0224 Kcals/kg/min. and 0.0254 Kcals/kg/min. for females and males respectively. This study also showed that the males had a 5.67% higher energy cost of standing than the females. This difference was lower than the 8% and 13% difference between the sexes reported by the same authors.

Comparison between the Energy Cost of Walking and Running.

Table 6 showed the mean optimal speed, exercise (walking or running) time, recovery time from exercise, oxygen consumption during the exercise as well as recovery periods, respiratory quotient (R.Q.) and the gross energy cost of walking and running in the females and males. The individual values are given in tables 54, 55, 56 and 57, Appendix F. In

females, the optimal walking speed ranged from 3.9751 kmh (66.25 metres/min.) to 5.1849 kmh (86.41 metres/min.) with the mean being 4.6398 kmh (77.33 metres/min.) (S.D.$\pm$ 0.0056 kmh or $\pm$ 5.56 metres/min.). The optimal running speed for these subjects ranged from 7.9769 kmh (132.95 metres/min.) to 9.5323 kmh (158.87 metres/min.) with the mean being 8.6211 kmh (143.69 metres/min.) (S.D. $\pm$ 0.0069 kmh or $\pm$ 6.90 metres/min.). In males, the corresponding values for walking were 3.9751 (66.25 metres/min.), 5.3976 kmh (89.96 metres/min.) and 4.8913 kmh (81.46 metres/min.) (S.D. $\pm$ 0.0068 kmh or $\pm$ 6.82 metres/min.), while for running these values were 7.7774 kmh (129.62 metres/min.), 10.8352 kmh (180.59 metres/min.) and 9.2936 kmh (154.89 metres/min.)(S.D. $\pm$ 0.121 kmh or $\pm$ 12.05 metres/min.). For both the groups of subjects, the mean optimal walking speeds obtained were within the range of optimal speeds given in Table 1, page 14. The mean optimal walking speed of the females, 77.33 metres/min., was higher than the mean value of 74 metres/min. obtained by Ralston (66) but lower than the mean value of 80 metres/min. obtained by Zarrugh, et al. (80). The mean optimal walking speed of the males, 81.46 metres/min., was higher than the mean values obtained by both Ralston (66) and Zarrugh, et al. (80), but was lower than the mean value of 83.33 metres/min. obtained by Corcoran and Brengelmann (22). It, however, was almost identical to the mean optimal speed of 81.5 metres/min. obtained by Blessey, et al. (7). The mean optimal running speed of the females and males in this study, 143.69 metres/min. and 154.89 metres/min. respectively, was considerably lower than the mean optimal running speed of 185 metres/min. determined by Mayhew (56) on his highly trained runners.

The time taken to walk the distance of one kilometre in the female subjects ranged from 11 minutes 34 seconds to 15 minutes 6 seconds with the mean being 13 minutes (S.D.± 58.36 seconds), while the time taken to run the same distance ranged from 6 minutes 18 seconds to 7 minutes 31 seconds, the mean being 6 minutes 58 seconds (S.D.± 19.46 seconds). In males, the corresponding values for walking were 11 minutes 7 seconds, 15 minutes 6 seconds and 12 minutes 21 seconds (S.D.± 67.82 seconds), while for running these were 5 minutes 32 seconds, 7 minutes 43 seconds and 6 minutes 30 seconds (S.D.± 18.05 seconds).

Comparing the volumes of oxygen consumed during the exercise period we find that even though the time taken to walk the one kilometre was almost twice that taken to run the same distance in both the groups, the oxygen consumption during this period was significantly less. In females for walking, the range was from 122.1 ml/kg to 184.4 ml/kg with the mean being 155.6 ml/kg (S.D.± 15.7 ml/kg). For running, the range was from 185.8 ml/kg to 269.3 ml/kg with the mean being 214.7 ml/kg (S.D.± 25.2 ml/kg). In males, the corresponding values for walking were 127.0 ml/kg,173.3 ml/kg and 151.2 ml/kg (S.D.± 14.5 ml/kg), while for running these were 165.7 ml/kg, 246.4 ml/kg and 194.7 ml/kg (S.D.± 23.3 ml/kg). The difference between the oxygen consumed during the walk and the run, 37.8% and 28.77% in females and males respectively, was due to the fact that the subjects were exercising at a higher intensity while running than while walking and consequently the demand for oxygen was also higher. At the steady state level of walking, the oxygen consumption per minute was approximately 3 to 4 times the oxygen consumption

per minute of standing determined prior to the walk. At the steady state level of running, however, the oxygen consumption per minute was approximately 8 to 9 times the mean standing oxygen consumption per minute determined prior to the run.

Since running involved working at a higher intensity than walking, the time taken to recover from the former was significantly longer than that taken to recover from the latter in both the groups of subjects. In females, the recovery time for walking ranged from 1 minute 36 seconds to 4 minutes 56 seconds, the mean being 2 minutes 40 seconds (S.D. $\pm$ 61.45 seconds). The recovery time for running ranged from 3 minutes 33 seconds to 12 minutes 52 seconds, the mean being 6 minutes 49 seconds (S.D.$\pm$ 180.35 seconds). The corresponding values in males for walking were 1 minute 26 seconds, 3 minutes 23 seconds and 2 minutes 14 seconds (S.D.$\pm$ 40.98 seconds) and for running these were 2 minutes 4 seconds, 11 minutes 20 seconds and 5 minutes 33 seconds (S.D.$\pm$ 172.53 seconds). The longer recovery time for running in both groups of subjects resulted in a significantly greater volume of oxygen being consumed during this period than during the recovery period from walking. In females, for walking,the recovery oxygen consumption ranged from 11.4 ml/kg to 22.0 ml/kg, the mean being 14.4 ml/kg (S.D.$\pm$ 3.56 ml/kg). For running, the range was from 27.6 ml/kg to 113.3 ml/kg, the mean being 53.9 ml/kg (S.D.$\pm$ 24.23 ml/kg). In males, the corresponding values for walking were 7.8 ml/kg, 19.1 ml/kg and 12.1 ml/kg (S.D.$\pm$ 3.31 ml/kg), while for running these values were 19.8 ml/kg, 73.2 ml/kg and 40.7 ml/kg (S.D.$\pm$ 14.41 ml/kg). The mean volume of oxygen consumed during the recovery period from walking was only 26.72% and 29.73% of the mean volume of

oxygen consumed during the recovery period from running for females and males respectively.

The gross energy cost of any activity is calculated from the oxygen consumed during the exercise as well as recovery periods. Comparing the total time during which oxygen consumption was measured for each of the two activities, i.e. the sum of the exercise time and recovery time, we find that in both the groups this was longer for walking than for running with the difference being significant only in the case of the males. In females, for walking the total time ranged from 14 minutes 30 seconds to 18 minutes, the mean being 15 minutes 40 seconds (S.D.$\pm$ 65.4 seconds). For running, the range was from 10 minutes 30 seconds to 20 minutes, the mean being 13 minutes 47 seconds (S.D.$\pm$ 180.6 seconds). The corresponding values in males for walking were 13 minutes, 18 minutes and 14 minutes 35 seconds (S.D.$\pm$ 85.8 seconds), while for running these were 8 minutes 30 seconds, 17 minutes 30 seconds, and 12 minutes 3 seconds (S.D.$\pm$161.4 seconds). In spite of the shorter total duration of measuring oxygen consumption for the running test, the total volume of oxygen consumed during this period was significantly greater than that consumed in the total duration of the walking test. In females, for walking, the values ranged from 133.5 ml/kg/km. to 198.4 ml/kg/km. the mean being 170 ml/kg/km. (S.D.$\pm$ 15.2 ml/kg/km.) while for running the values ranged from 215 ml/kg/km. to 382.6 ml/kg/km. the mean being 268.6 ml/kg/km. (S.D.$\pm$ 48.8 ml/kg/km.) In males, the corresponding values for walking were 134.8 ml/kg/km, 188.8 ml/kg/km. and 163.3 ml/kg/km. (S.D.$\pm$16.7 ml/kg/km.), while for running these values were 203.7 ml/kg/km, 279.7 ml/kg/km. and 235.4 ml/kg/km. (S.D.$\pm$ 24.0 ml/kg/km). It is evident from these values that the mean

gross oxygen cost of running was 58% and 44.15% more expensive than the mean gross oxygen cost of walking in females and males respectively.

Converting these values of oxygen consumption into Kilocaloric equivalents, we find that the gross energy cost of walking in females ranged from 0.6430 Kcals/kg/km. to 0.9718 Kcals/kg/km. with most of the values centering around the mean which was 0.8224 Kcals/kg/km. (S.D.$\pm$ 0.077 Kcals/kg/km.). For the same group of subjects, the energy cost of running showed more variation. The range was from 1.0487 Kcals/kg/km. to 1.8721 Kcals/kg/km., with the mean being 1.3221 Kcals/kg/km. (S.D. $\pm$ 0.239 Kcals/kg/km.). In males, the gross energy cost of walking seemed to follow the same pattern as in the females. The range was from 0.6803 Kcals/kg/km. to 0.9123 Kcals/kg/km. with the mean being 0.7948 Kcals/kg/km. (S.D.$\pm$ 0.072 Kcals/kg/km). The male subjects did not show as great a variation as the females in the gross energy cost of running. The range was from 1.0175 Kcals/kg/km. to 1.3572 Kcals/kg/km., the mean being 1.1596 Kcals/kg/km. (S.D.$\pm$ 0.015 Kcals/kg/km.). Comparing the values of walking with running, we find that the latter was 60.76% and 45.89% more expensive than the former in females and males respectively. Figure 5 shows this comparison graphically.

The slight discrepancy in the percentages obtained between the two methods of comparing walking with running, namely, gross oxygen cost and gross energy cost, was because of the conversion factor used in transforming oxygen consumption values into Kilocaloric equivalents. The mean respiratory quotient for the walk, 0.83 in females and 0.86 in males, was less than that for the run, 0.91 in both groups of subjects. Carpenter's (15) tables show that as the respiratory quotient increases,

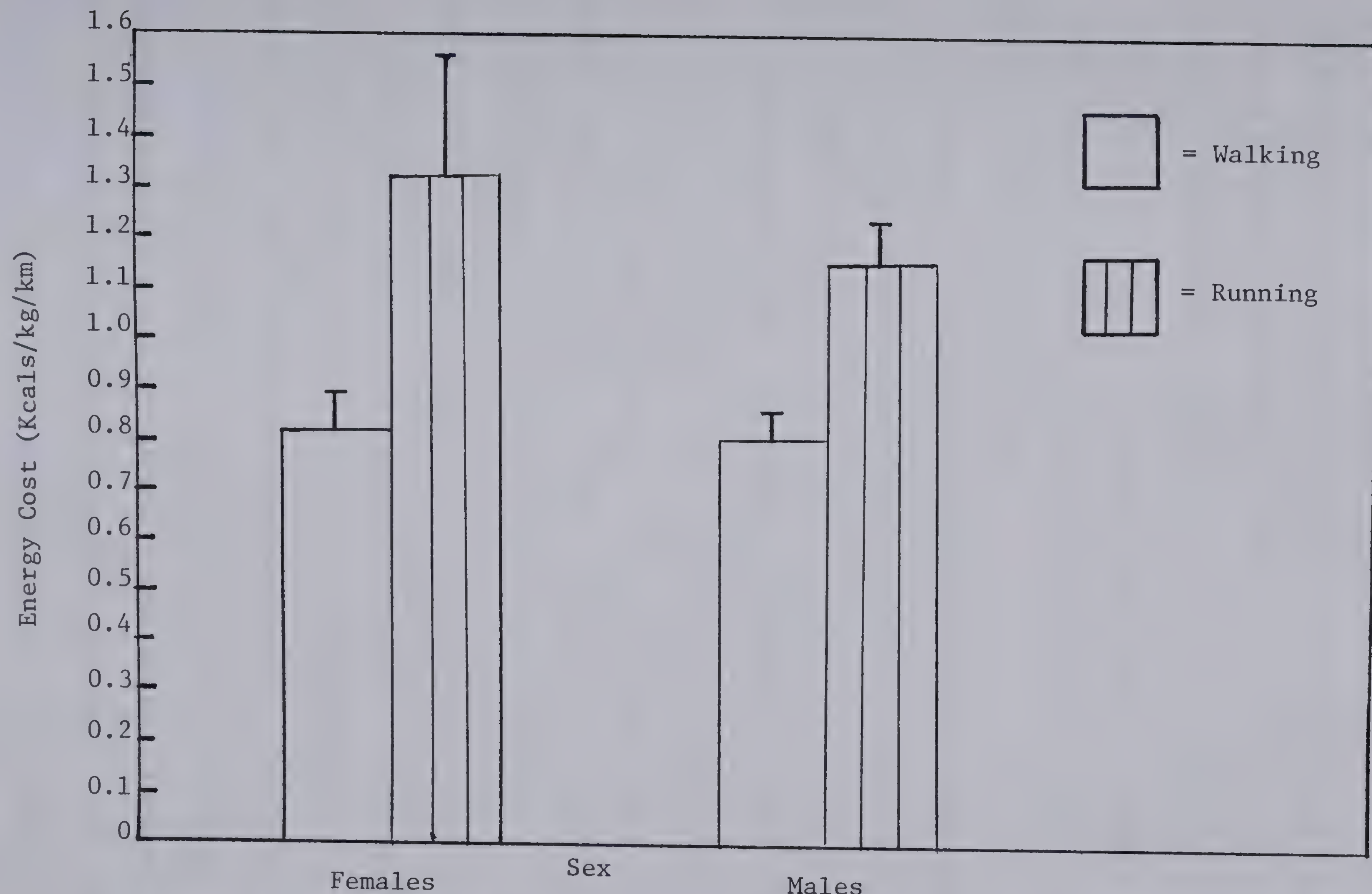

Figure 5 - Comparison Between the Gross Energy Costs of Walking and Running One Kilometre in Females and Males.

the Kilocaloric equivalent for one litre of oxygen also increases. Therefore, the conversion factor used for running was higher than that used for walking. Consequently, the percentages obtained when the costs were expressed in Kilocalories were slightly higher than those obtained when the costs were expressed in millilitres of oxygen. It should be mentioned that in several instances during the recovery period of the run, the R.Q. values obtained were greater than one. In such cases, the conversion factor corresponding to an R.Q. of one was used in calculating the energy costs.

The mean net energy costs(gross energy costs minus standing energy costs for the total duration of the activity) of walking and running in the females and males were given in table 30. The individual values are given in tables 58, 59, 60 and 61, Appendix F. These values seemed to follow a trend similar to that of the gross energy costs. In females, for walking, the range was from 0.3665 Kcals/kg/km. to 0.6626 Kcals/kg/km., with the mean being 0.5258 Kcals/kg/km. (S.D.$\pm$ 0.069 Kcals/kg/km.), while for running, the range was from 0.8139 Kcals/kg/km. to 1.4427 Kcals/kg/km., with the mean being 1.0505 Kcals/kg/km. (S.D.$\pm$ 0.182 Kcals/kg/km). In males, for walking, the range was from 0.3594 Kcals/kg/km. to 0.6616 Kcals/kg/km. with the mean being 0.4931 Kcals/kg/km. (S.D.$\pm$ 0.068 Kcals/kg/km.), while for running, the range was from 0.7912 Kcals/kg/km. to 1.1178 Kcals/kg/km. with the mean being 0.9233 Kcals/kg/km. (S.D.$\pm$ 0.084 Kcals/kg/km.). For both the sexes, the difference between the net energy cost of walking and running was highly significant. The results of this study, therefore, rejected the null hypothesis that there would be no significant difference in the net energy cost of walking and running a

distance of one kilometre for both females and males. From the values obtained, it was evident that the net energy cost of running was 99.79% and 87.24% greater than that of walking in females and males respectively. Figure 6 shows this comparison graphically.

The energy cost per step was given by the ratio of the energy cost per kilometre and the step frequency per kilometre. The mean values of the gross and net energy costs per step of walking and running in females and males were given in table 35. The individual values are available in tables 62, and 63, Appendix F. A comparison between the energy cost per step of the two activities showed that the differences were even more exaggerated. For convenience, the gram calorie (cal.) was used as the unit of energy instead of the Kilocalorie (1 Kilocalorie is equivalent to 1000 gram calories). In females, the gross energy cost per step of running was 112.5% greater than that of walking. The range for walking was from 0.4853 cals/kg/step to 0.6652 cals/kg/step with the mean being 0.5707 cals/kg/step (S.D.$\pm$ 0.047 cals/kg/step) while for running the corresponding values were 0.9009 cals/kg/step, 1.6153 cals/kg/step and 1.2117 cals/kg/step (S.D.$\pm$ 0.233 cals/kg/step). In males, the gross energy cost per step of running proved to be 89.74% more expensive than that of walking. The values for walking ranged from 0.4871 cals/kg/step to 0.6782 cals/kg/step with the mean being 0.5938 cals/kg/step (S.D.$\pm$ 0.063 cals/kg/step). The corresponding values for running were 0.8940 cals/kg/step, 1.3358 cals/kg/step and 1.1267 cals/kg/step (S.D.$\pm$ 0.190 cals/kg/step). For both the groups of subjects the differences between the two activities were highly significant. These comparisons are illustrated in Figure 7. A comparison between the net

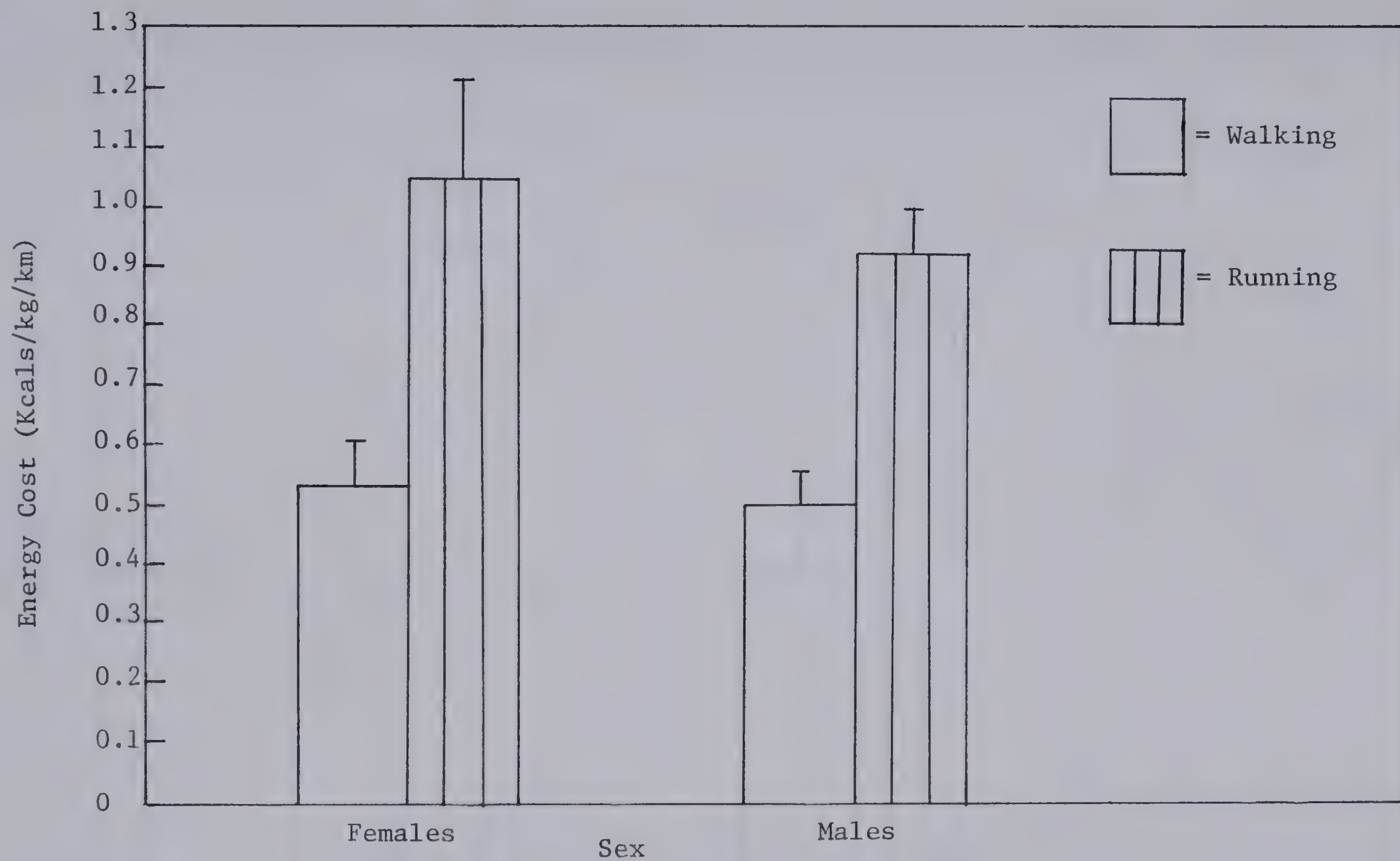

Figure 6 - Comparison Between the Net Energy Costs of Walking and Running One Kilometre in Females and Males.

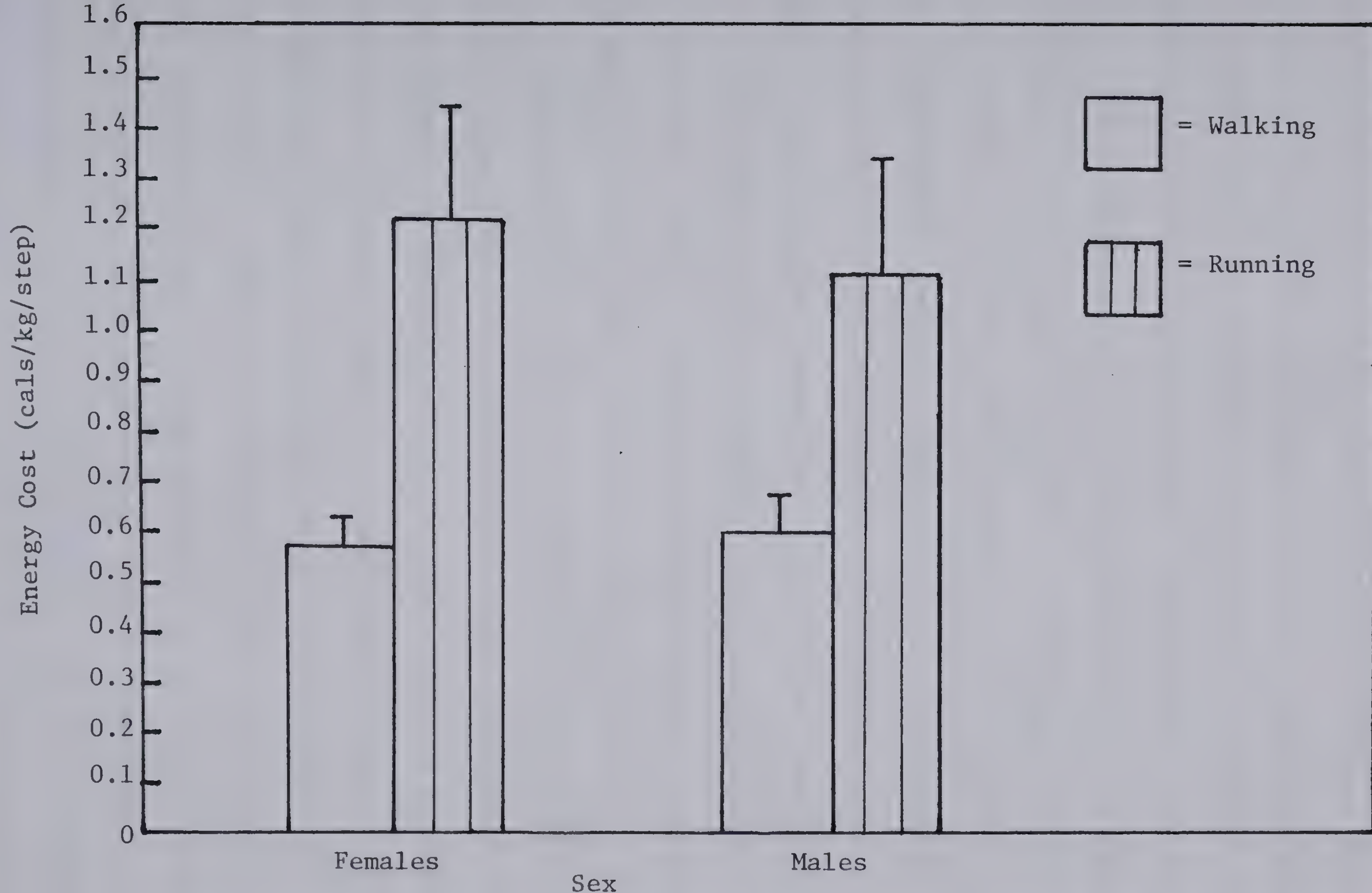

Figure 7 - Comparison Between the Gross Energy Costs of Walking and Running One Step in Females and Males.

energy cost per step of the two activities showed that the differences were even more phenomenal. Running exceeded walking by 163.7% and 144.16% in females and males respectively. In females, the range for walking was from 0.2766 cals/kg/step to 0.4535 cals/kg/step with the mean being 0.3654 cals/kg/step (S.D.$\pm$ 0.049 cals/kg/step). The corresponding values for running were 0.6992 cals/kg/step, 1.2448 cals/kg/step and 0.9638 cals/kg/step (S.D.$\pm$ 0.185 cals/kg/step). In males, for walking, the values ranged from 0.2850 cals/kg/step to 0.5062 cals/kg/step with the mean being 0.3673 cals/kg/step (S.D.$\pm$ 0.068 cals/kg/step). The corresponding values for running were 0.7174 cals/kg/step, 1.1421 cals/kg/step and 0.8968 cals/kg/step (S.D.$\pm$ 0.154 cals/kg/step). Once again, the differences between the two activities were highly significant in both the groups of subjects. These comparisons are illustrated in Figure 8. Table 41 summarises the comparisons of the energy costs of the two activities by the different methods discussed.

Cavagna and Kaneko (16) have shown that except at the higher speeds (above 20 kmh), the total mechanical work and energy cost of running a unit distance at a given speed was greater than that of walking the same distance at a similar speed. Cotes and Meade(23) have shown that the energy cost of walking was proportional to the vertical lift of the trunk. The vast difference between the energy cost of walking and running observed in this study was probably due to the difference in the vertical lift of the two activities. Table 6 showed the mean vertical lift per step as well as the mean vertical lift per kilometre of walking and running in the female and male subjects. The individual values are given in tables 50, 51, 52 and 53, Appendix F. In females, for walking,

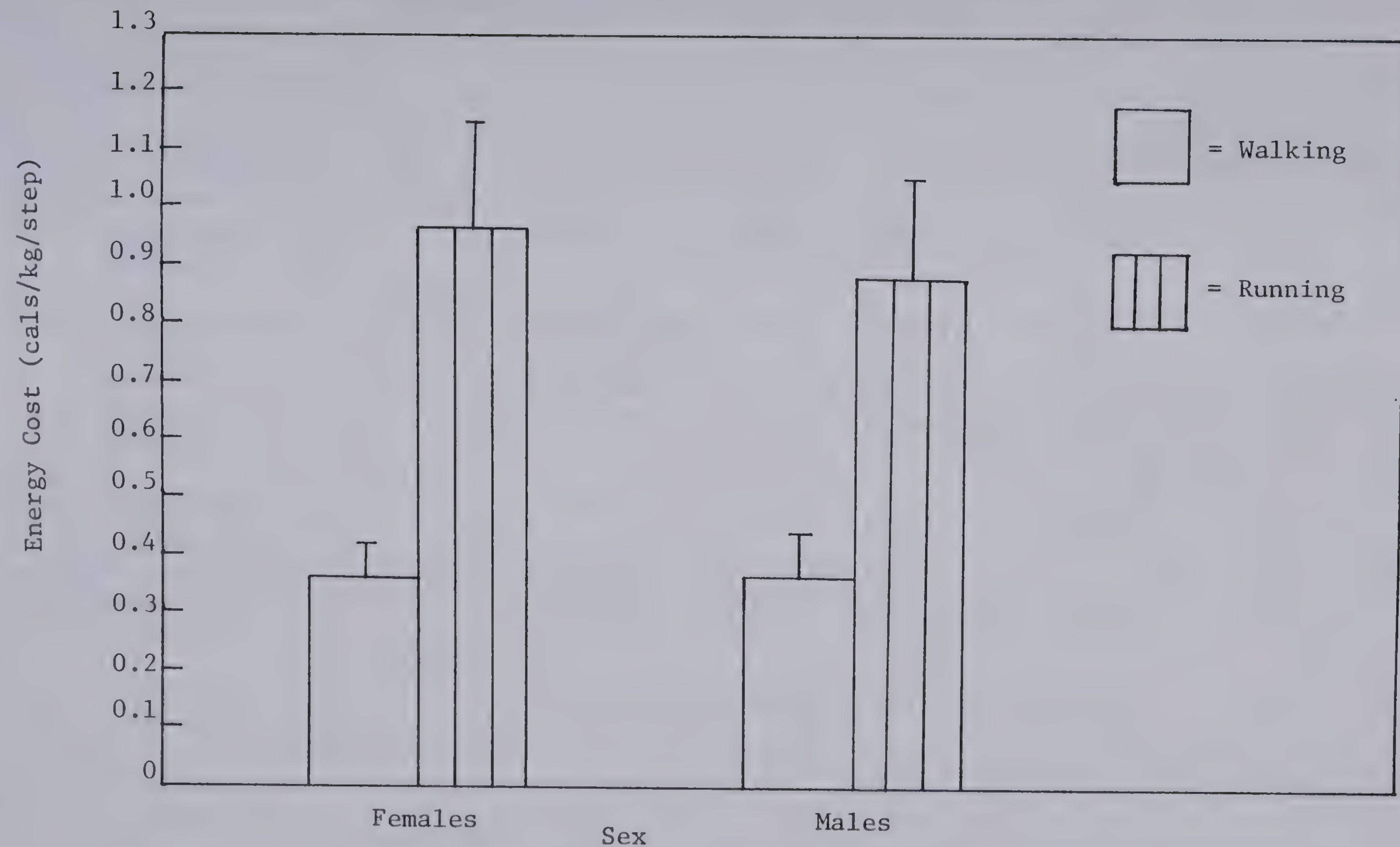

Figure 8 - Comparison Between the Net Energy Costs of Walking and Running One Step in Females and Males.

Table 41 - Comparison Between the Energy Cost of Walking and Running by the Different Methods.

Method of Comparison	Sex	Walking	Running	Percentage Difference (Running>Walking)
Gross Energy Cost per Kilometre	Female	0.8224 Kcals/kg/km.	1.3221 Kcals/kg/km.	60.76
Gross Energy Cost per Step		0.5707 cals/kg/step	1.2117 cals/kg/step	112.3
Gross Energy Cost per Kilometre	Male	0.7948 Kcals/kg/km.	1.1596 Kcals/kg/km.	45.89
Gross Energy Cost per Step		0.5938 cals/kg/step	1.1267 cals/kg/step	89.74
Net Energy Cost per Kilometre	Female	0.5258 Kcals/kg/km.	1.0505 Kcals/kg/km.	99.79
Net Energy Cost per Step		0.3654 cals/kg/step	0.9638 cals/kg/step	163.76
Net Energy Cost per Kilometre	Male	0.4931 Kcals/kg/km.	0.9233 Kcals/kg/km.	87.24
Net Energy Cost per Step		0.3673 cals/kg/step	0.8968 cals/kg/step	144.16

the vertical lift per step ranged from 2.34 cms. to 4.78 cms. with the mean being 3.15 cms. (S.D.$\pm$ 0.739 cms.). The corresponding values for running were 7.04 cms., 10.93 cms. and 8.89 cms. (S.D.$\pm$ 1.212 cms.). In males, for walking, the values ranged from 2.77 cms. to 4.70 cms. with the mean being 3.31 cms. (S.D.$\pm$ 0.579 cms.), while for running, the corresponding values were 6.10 cms., 11.49 cms. and 8.80 cms. (S.D.$\pm$ 1.464 cms.). In both the groups of subjects, the vertical lift per running step was significantly greater than that per walking step.

The vertical lift per kilometre was given by the product of the vertical lift per step and the step frequency per kilometre. Although the walking step frequency was significantly greater than the running step frequency in both females and males, the vertical lift per kilometre was significantly greater in the latter activity for both the sexes. In females, for walking, the vertical lift per kilometre ranged from 3514.66 cms. to 6496.02 cms. with the mean being 4507.39 cms. (S.D.$\pm$ 886.81 cms.). The corresponding values for running were 8064.78 cms., 11104.88 cms. and 9717.90 cms. (S.D.$\pm$1151.39 cms.). In males, for walking, the range was from 3526.21 cms. to 5926.70 cms. with the mean being 4442.93 cms. (S.D.$\pm$ 645.23 cms.). The corresponding values for running were 6801.50 cms., 10926.90 cms. and 9087.17 cms. (S.D.$\pm$1086.59 cms.).

Table 42 compares the ratio of the mean net energy cost of running and walking one kilometre with the ratio of the mean vertical lift per kilometre of the two activities in females and males. In each case the ratio is approximately 2. Table 43 compares the ratio of the mean net energy cost per step of running and walking with the ratio of the mean

Table 42 - Comparison Between the Ratio of the Net Energy Cost of Running and Walking One Kilometre and the Ratio of the Vertical Lift Per Kilometre of Running and Walking.

Sex	Net Energy Cost per Kilometre (Kcals/kg/km.)		$\frac{\text{Running}}{\text{Walking}}$	Vertical Lift per Kilometre (cms.)		$\frac{\text{Running}}{\text{Walking}}$
	Walking	Running		Walking	Running	
Female	0.5258	1.0505	1.9979	4507.39	9717.90	2.1559
Male	0.4931	0.9233	1.8724	4442.93	9087.17	2.0453

Table 43 - Comparison Between the Ratio of the Net Energy Cost Per Step of Running and Walking and the Ratio of the Vertical Lift Per Step of Running and Walking.

Sex	Net Energy Cost per Step (cals/kg/step)		$\frac{\text{Running}}{\text{Walking}}$	Vertical Lift per Step (cms.)		$\frac{\text{Running}}{\text{Walking}}$
	Walking	Running		Walking	Running	
Female	0.3644	0.9569	2.6259	3.15	8.89	2.8222
Male	0.3651	0.8999	2.4648	3.31	8.80	2.6586

vertical lift per step of the two activities in females and males. With the exception of the ratio of the vertical lift per step of running and walking in females, all the other ratios are approximately 2.5. From these observations we can generally state that the proportionality between the net energy costs of running and walking are approximately equal to the proportionality between their vertical lifts.

On comparing the results of the present study with those of Howley and Glover's (46), it was found that the two were in general agreement with each other. Both the studies have indicated that the net energy expended in running a distance of one kilometre was almost twice that expended in walking the same distance. However, the values obtained in the present study were higher than those obtained by Howley and Glover (table 44). In females, for walking and running, the gross values obtained in this study were higher by 15.13% and 23.04% respectively, while in males, they were higher by 18.49% and 18.19%. These differences were probably due to the fact that in the present study recovery oxygen consumption values (oxygen debts) were used in calculating the energy costs of the activities while in the study by Howley and Glover, steady state oxygen consumption measurements were used. On comparing the net energy costs of these activities in the two studies, we found that the values obtained were quite similar (table 44). This was because Howley and Glover deducted a lower basal value, the energy cost of lying rest, from the gross value to obtain the net energy cost, whereas in the present study a higher basal value, the energy cost of standing at 'ease', was deducted to calculate the net energy cost.

Margaria, et al. (54) claimed that the net energy cost of running

Table 44 - Comparison between Present Study and Howley and Glover's Study

Sex	Activity	Optimal Speed metres/minute		Gross Energy Cost Kcals/kg/km.		Net Energy Cost Kcals/kg/km.	
		(1)	(2)	(1)	(2)	(1)	(2)
Female	Walking	77.33±5.56	82±3	0.8224±0.077	0.7143±.050	0.5258±0.069	0.5155±.050
	Running	143.69±6.90	137±4	1.3221±0.239	1.0745±.056	1.0505±0.182	0.9503±.056
Male	Walking	81.46±6.82	82±3	0.7948±0.072	0.6708±.038	0.4931±0.068	0.4720±.044
	Running	154.89±12.05	195±25	1.1596±0.105	0.9752±.056	0.9233±0.084	0.8882±.050

(1) Present Study; (2) Howley and Glover's Study

Values are Means ± Standard Deviations

did not vary with speed and was twice that of walking at the optimal speed. The values that these researchers quoted, without differentiating between the sexes, were 1 Kcal/kg/km. for running and 0.5 Kcals/kg/km. for walking. The combined mean values of females and males obtained in this study, 0.5095 Kcals/kg/km. for walking and a 0.9869 Kcals/kg/km. for running matched these values very closely.

Comparison between Females and Males.

a) Walking

A comparison of the mean gross energy cost of walking one kilometre between females and males revealed that there was no significant difference between the two groups. Prior to walking, the mean energy cost for one minute of standing was 9.47% higher in the males than in the females (0.0208 Kcals/kg/min. vs. 0.0190 Kcals/kg/min.). This difference between the sexes was not significant. On comparing females and males for the energy cost of standing for the total duration of the walk, it was found that the difference between the sexes was reduced to 1.78% (0.3018 Kcals/kg vs. 0.2965 Kcals/kg). This was because of the significantly longer duration of the walking test of the female subjects (15 mins. 40 secs. vs. 14 mins. 35 secs.). Despite their lower standing energy cost, the females had a 3.47% higher gross energy cost of walking than the males (0.8224 Kcals/kg/km. vs. 0.7948 Kcals/kg/km.). The females probably compensated for their lower standing energy cost by (a) doing a slightly greater amount of lift work, as reflected by the vertical lift per kilometre, and (b) by doing a significantly greater amount of muscular work as reflected by the step frequency. It has already been established in this study that the energy costs of walking and running were approximately proportional to

their vertical lifts. The vertical lift per kilometre in the females was 4507.39 cms. compared to a value of 4442.93 cms. in the males. This difference of 1.45% between the sexes was insignificant. Falls and Humphrey (33) claimed that a higher step frequency would result in a greater amount of heat being dissipated and consequently increase the energy cost. The females in this study took 1442.66 steps to walk the distance of one kilometre while the males took 1350.66 steps to travel the same distance. This difference of 6.81% between the sexes was significant.

After deducting the energy cost of standing from the gross energy cost of walking to obtain the net energy cost, the difference between the sexes increased to 6.63% (0.5258 Kcals/kg/km. vs. 0.4931 Kcals/kg/km.) but was still insignificant. This was not surprising because the difference between the sexes in the energy cost of standing for the total duration of the walking test was not significant. Figure 9 illustrates the comparisons between females and males for the gross and net energy costs of walking one kilometre.

On comparing the gross as well as net energy costs per step of walking between females and males, the trend seemed to reverse. In both instances, the mean values obtained for males were higher than those obtained for females, but once again the differences were insignificant. The gross energy cost per step of walking was 4.05% higher in the males than in the females (0.5938 cals/kg/step vs. 0.5707 cals/kg/step), while the net energy cost per step was only 0.52% higher in the same group of subjects (0.3673 cals/kg/step vs. 0.3654 cals/kg/step). The greater energy cost per walking step of the males was probably due to their 5.07%

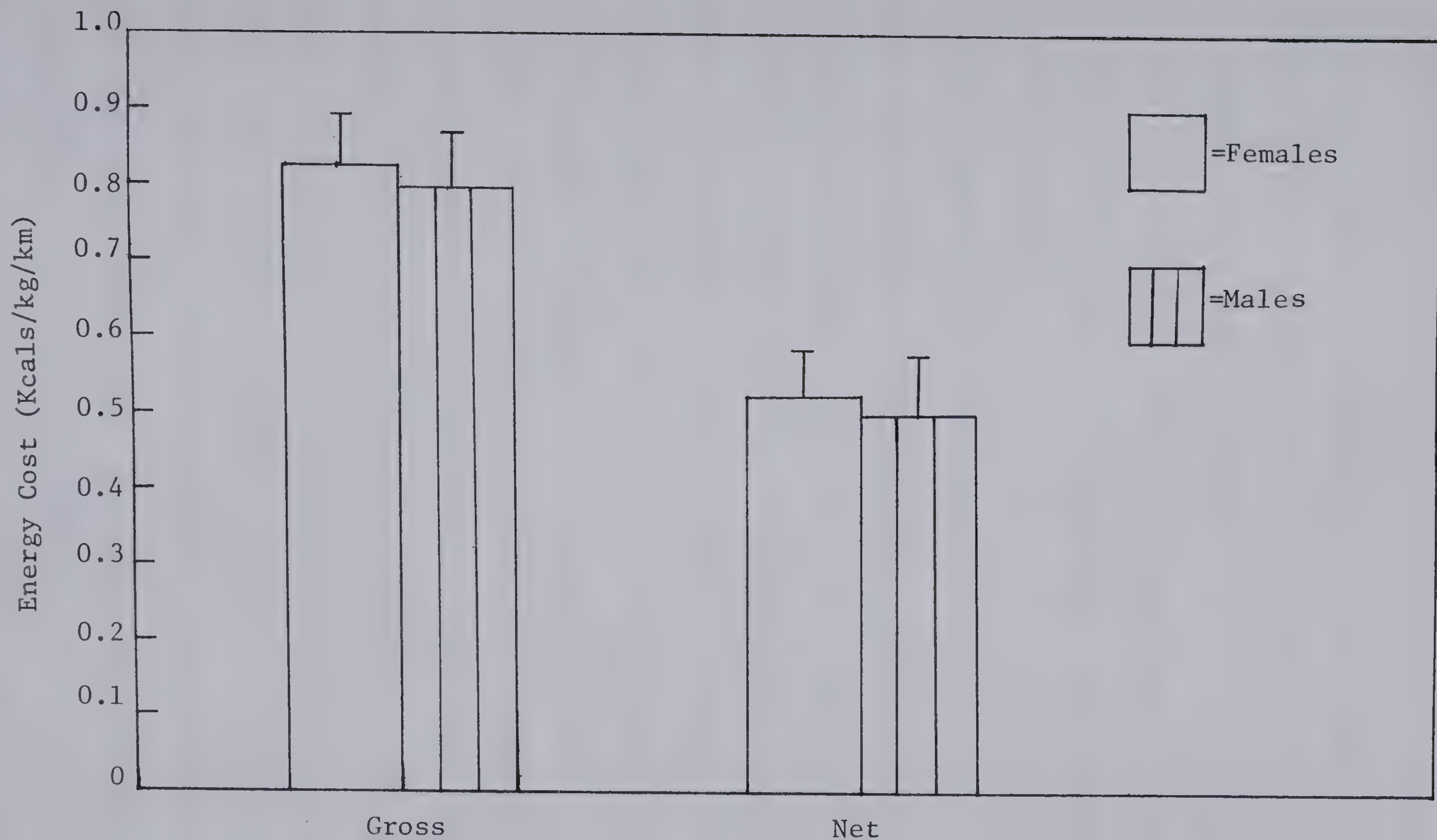

Figure 9 - Comparison Between Females and Males for the Gross and Net Energy Costs of Walking One Kilometre.

higher vertical lift per step (3.31 cms. vs. 3.15 cms.). These comparisons are illustrated in figure 10.

The results of the sex comparisons for the energy cost of walking obtained in this study were similar to those reported by Blessey, et al. (7), Durnin and Namyslowski (30), Mahadeva, et al. (53), Ralston (65) and Zarrugh, et al. (80). All these studies claimed, just as this one did, that there was no significant difference between females and males in the gross and/or net energy cost of walking a unit distance. Results contradictory to these were obtained by Booyens and Keatinge (10), Gehlsen and Dill (30), McDonald (57) and Howley and Glover (46). The first three studies showed that the energy cost of walking a unit distance was higher in males than in females, while the last study showed the opposite. Booyens and Keatinge (10) attributed the 12% greater gross energy cost of walking in the males to their apparently greater vertical lift per step, which they felt was a consequence of their longer step lengths. Although the cinematographic analysis in this study did show a higher vertical lift per step in the males, this difference between the sexes was insignificant. In fact, the significantly shorter step length of the females resulted in them taking more steps to walk the same distance as the males, and consequently the total vertical lift per kilometre was higher in the former group of subjects. Gehlsen and Dill (39) attributed the higher gross energy cost of the males to their 13% higher standing energy cost. This study showed that, for the total duration of the walking test, the males had a 1.78% higher standing energy cost than the females, and in spite of this their energy cost was lower. Even if the males did have a 13% higher standing energy cost than the females, the differences in the

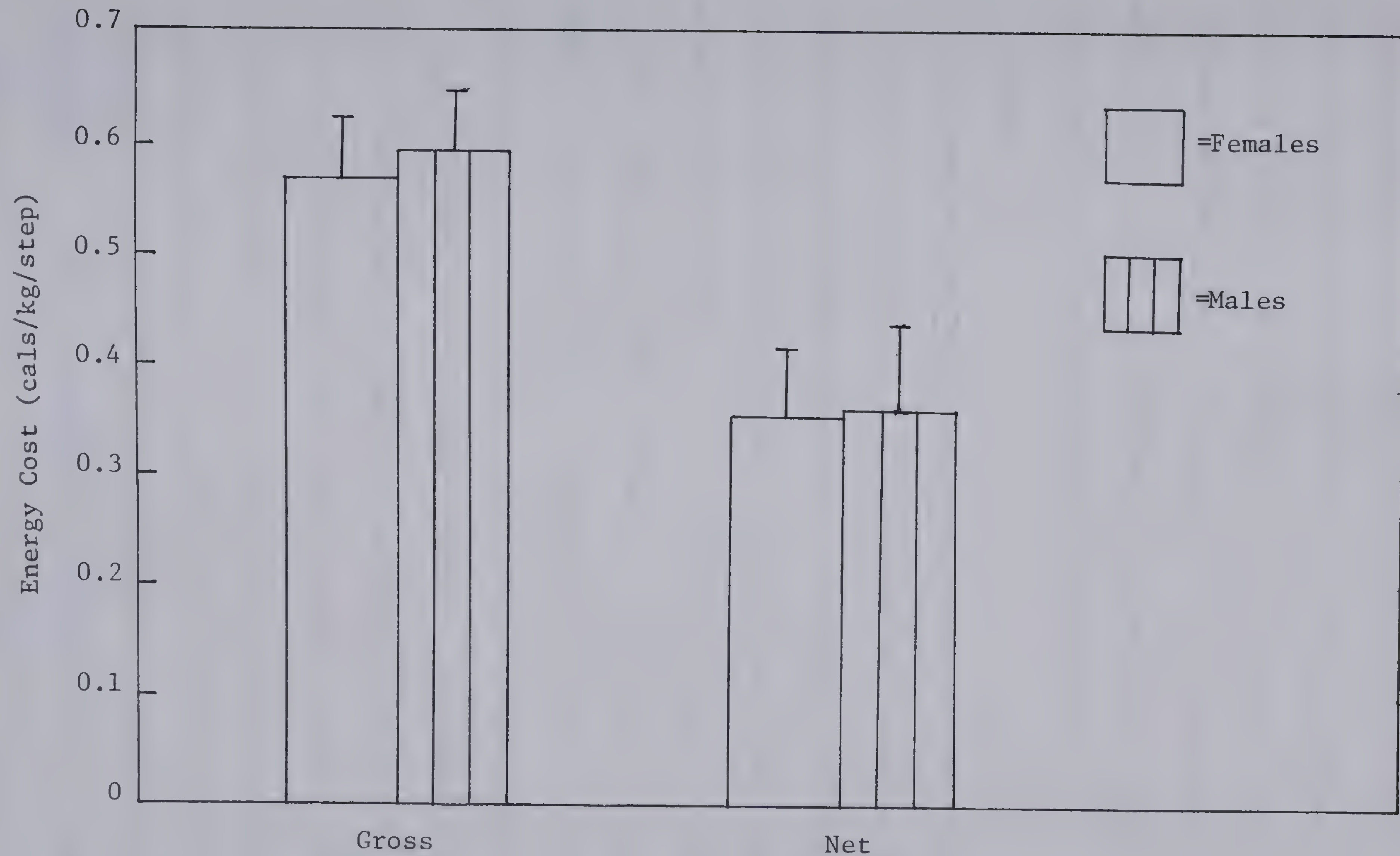

Figure 10 - Comparison Between Females and Males for the Gross and Net Energy Costs of Walking One Step.

gross energy cost of walking between the sexes would have been insignificant. The study by Howley and Glover (46) was the only one which indicated that both the gross and net energy costs of walking were significantly greater in females than in males, but these authors were unable to offer any explanation for their results. Although this study did show the gross and net energy costs of walking to be higher in females than in males, the differences between the sexes weren't of sufficient magnitude to be statistically significant.

b) Running

A comparison between females and males for the energy costs of running one kilometre revealed that both the gross and net values were significantly different between the two groups. Although the mean energy cost for one minute of standing prior to running was 2.02% higher in the males (0.0202 Kcals/kg/min. vs. 0.0198 Kcals/kg/min.), the females had a 10.72% higher energy cost of standing (not significant) for the total duration of the run (0.2715 Kcals/kg/km. vs. 0.2452 Kcals/kg/km.). This was because of the longer total duration of the running test for the females (13 mins. 47 secs. vs. 12 mins. 3 secs.). The higher standing energy cost of the females for the total duration of the run partially accounted for their 14.01% higher gross energy cost of running. After deducting this cost to obtain the net energy cost, it was found that the difference between the sexes was still significant. The females had a 13.77% higher net energy cost of running than the males (1.0505 Kcals/kg/km. vs. 0.9233 Kcals/kg/km.). These comparisons are illustrated in figure 11.

The fact that even the net energy cost of running was significantly different between the females and males implies that the difference be-

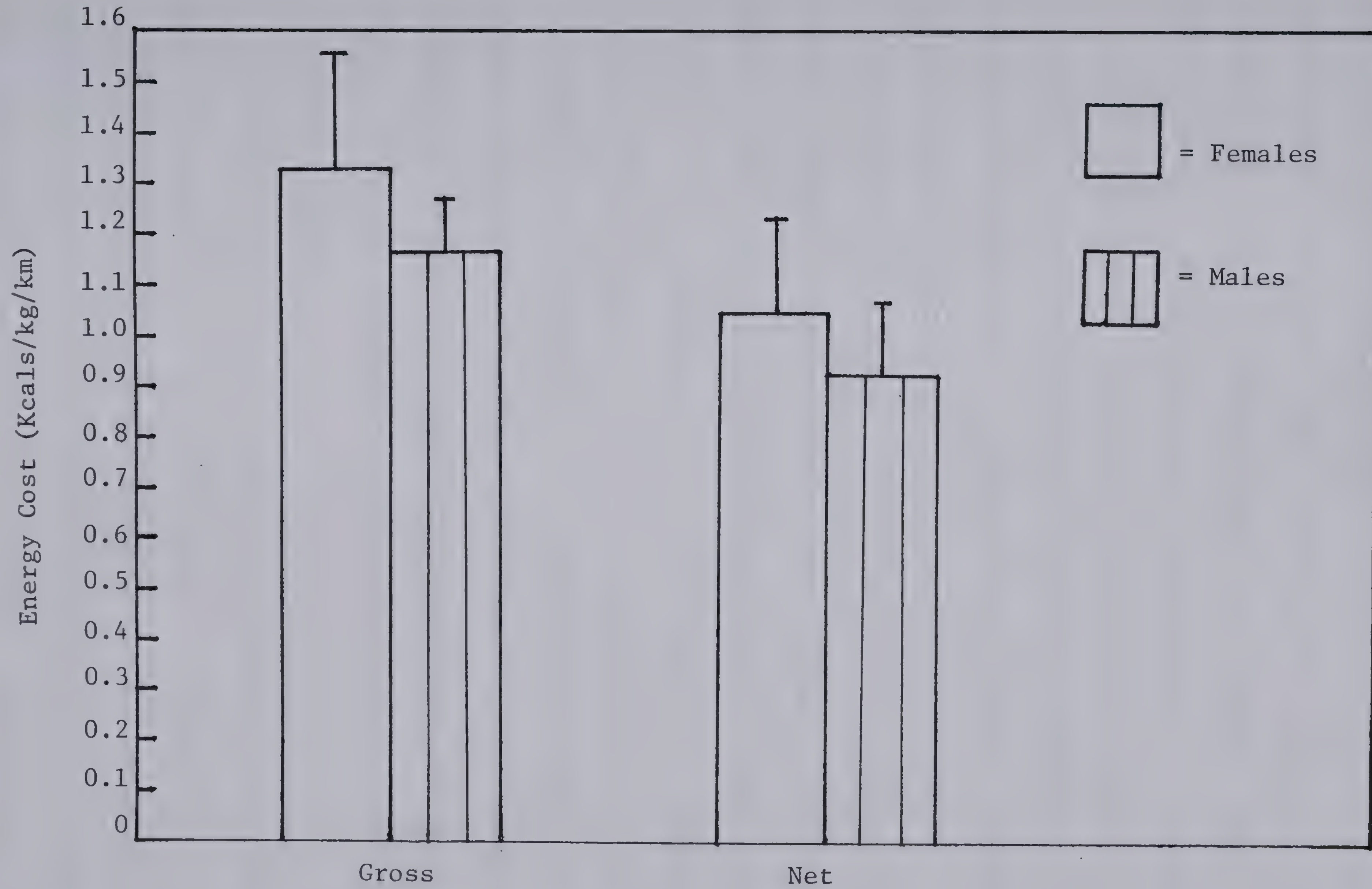

Figure 11 - Comparison Between Females and Males for the Gross and Net Energy Costs of Running One Kilometre.

tween the sexes was due to factors other than the energy cost of standing. Just as in the case of walking, the higher energy cost of running of the females was probably due to (a) their 6.94% greater amount of lift work, as reflected by their vertical lift per kilometre of running (9717.90 cms. vs. 9087.17 cms.) and (b) their 7.01% greater amount of muscular work, as reflected by their step frequency (1097.83 steps vs. 1025.91 steps). Although neither the vertical lift per kilometre nor the step frequency of running was significantly different between the two groups, it was quite possible that the combined effects of these two variables did result in a significantly greater amount of energy being expended by the females.

On comparing the energy cost per step of running between the two groups, slightly different results were obtained. Even though the females had a 7.54% higher gross energy cost per step (1.2117 cals/kg/step vs. 1.1267 cals/kg/step) and a 7.4% higher net energy cost per step (0.9638 cals/kg/step vs. 0.8968 cals/kg/step), neither of these differences were significant. This observation seemed quite reasonable because there was no significant difference in the vertical lift per running step between the females and males (8.89 cms. vs. 8.80 cms.). Figure 12 compares females and males for the gross and net energy costs of running one step.

Margaria, et al. (54) claimed that training lowered the energy cost of running by 6 to 8% simply because it resulted in a more efficient mode of movement. Bransford and Howley (12) felt that trained runners had lower energy costs than untrained runners because of their lower vertical displacement of the body per running step. Astrand and Rodahl (4) suggested that the repayment of an oxygen debt was inversely

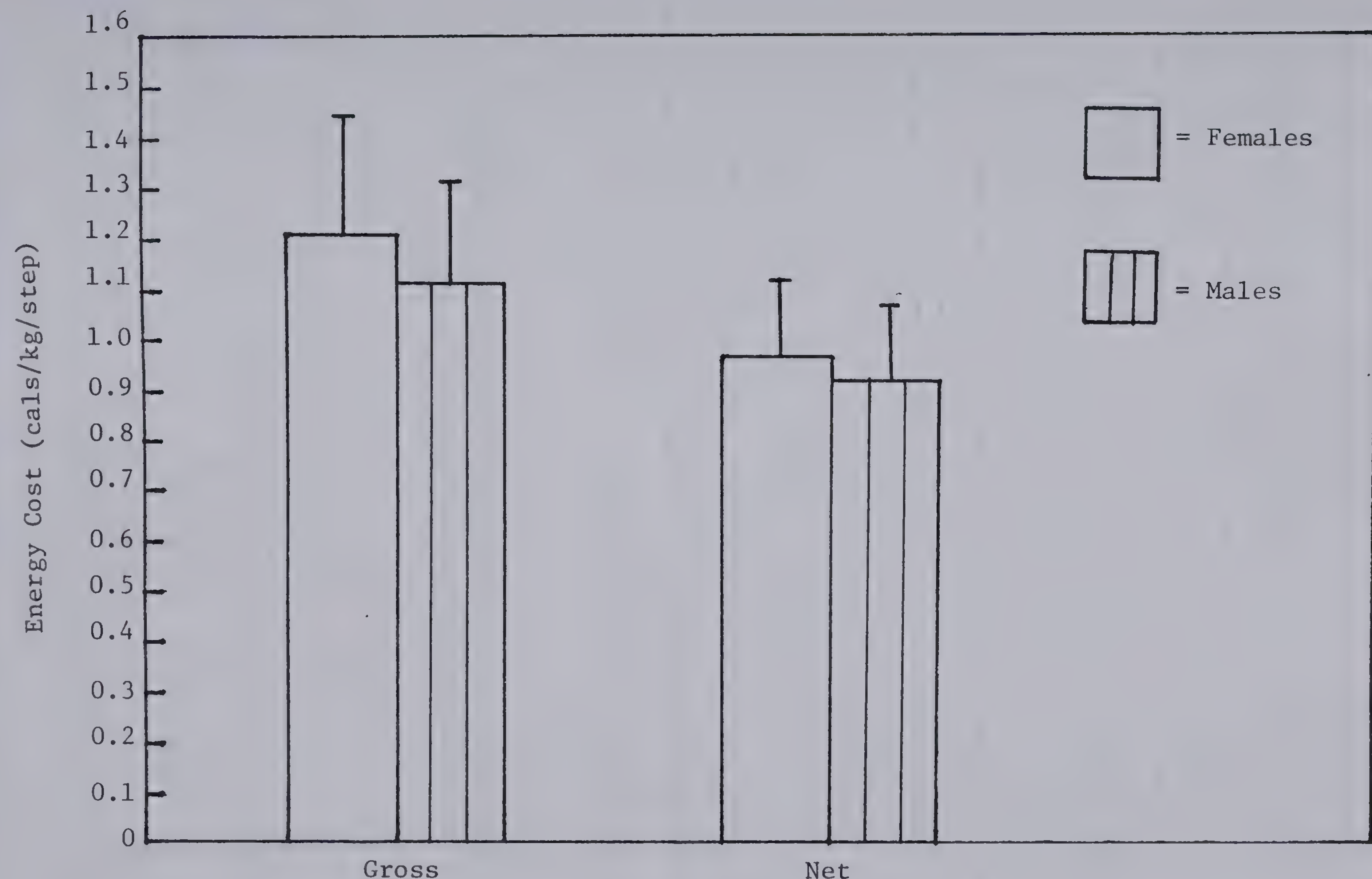

Figure 12 - Comparison Between Females and Males for the Gross and Net Energy Costs of Running One Step.

proportional to the level of training of the individual. The level of training of the two groups in this study, as indicated by their predicted maximum oxygen uptakes, did not differ significantly (table 45). The facts that there were no significant differences between females and males in the vertical displacement per running step and in the oxygen debt of running also indicated that there was no real difference in the training level between the two groups. Despite this, the energy cost of running the distance of one kilometre was higher in the female subjects. One is therefore tempted to state that the higher energy cost of running of the females was due to their natural running gait. Perhaps the shorter leg length of the female group resulted in a shorter step length which necessitated a greater number of steps to run the distance of one kilometre. The higher step frequency of the females, as already seen, could have been instrumental in increasing their energy cost by increasing the amount of lift work as well as muscular work.

Table 45 - Comparison of the Predicted Maximum Oxygen Uptakes Between Females and Males

Sex	Mean VO_2 max. ml/kg/min.	S.D. ml/kg/min	't'	P
Female	51.76	$\pm$ 9.52	-1.194	0.123
Male	56.12	$\pm$8.35		

Bransford and Howley (12) as well as Howley and Glover (46) attributed the higher gross and/or net energy cost of running a unit distance

in the females to their higher vertical lift per step. Although this study did report a higher gross and net energy cost of running a distance of one kilometre in females, the reason given was different. Durnin (29) as well as Falls and Humphrey (33) disagreed with these results when they stated that there was no significant difference in the gross or net energy cost of running between the sexes.

The overall comparisons of the energy costs of walking and running indicated that if the energy costs were expressed in units of distance (Kcals/kg/km.), then (a) there was no significant difference between females and males in either the gross or net energy cost of walking and (b) the gross and net energy cost of running was significantly greater in the females than in the males. If, however, the energy costs were expressed in units of steps (cals/kg/step), then the differences between females and males in the gross or net energy costs of walking and running were insignificant. Since the secondary null hypothesis established earlier in the study was to compare females and males for the energy cost of walking and running a unit distance, one must reject this hypothesis only for running and not for walking.

CHAPTER 5

SUMMARY AND CONCLUSIONS

Summary

The purpose of this study was (1) to compare the energy cost of walking and running a distance of one kilometre in females and males, when the subjects were allowed to choose their optimal (supposedly most economical) speeds and (2) to compare females and males for the energy cost of walking and running a distance of one kilometre at their optimal speeds. The energy costs of walking and running were to be calculated from the total volumes of oxygen consumed during the exercise as well as recovery periods.

A total of 24 active volunteers, 12 female and 12 male, participated in this study. Each one of them was subjected to 4 testing sessions. Briefly, the purpose of each session was as follows.

Session 1.

(a) To predict the subjects maximal oxygen uptake using the Astrand-Rhyming (5) bicycle test and (b) to estimate the subjects body fat using the hydrostatic method described by Sloan (72) and the density formula of Brozek and Keys (14).

Session 2.

To subjectively determine the subjects optimal walking and running speeds on the level treadmill and calculate the time that the treadmill belt would take to travel a distance of one kilometre at the speed selected.

Sessions 3 and 4.

(a) To determine the oxygen uptake for 5 minutes of standing at 'ease' on the treadmill and calculate the average oxygen consumption for one minute (b) to determine the total oxygen consumption (oxygen consumed during the exercise as well as recovery periods) of the one kilometre walk or run (c) to determine the average vertical lift of 6 walking or running steps by filming the subject after he or she had travelled 1/4 kilometre and 3/4 kilometre and (d) to count the step frequency for 2 minutes of the activity so that the step frequency per kilometre of distance travelled could be calculated.

The data collected was subjected to a two-way analysis of variance with repeated measures on one factor and the significant 'F' ratios were subjected to the appropriate 't' test to locate the differences.

Conclusions

Within the limitations of this study, the following conclusions seemed justifiable only at the optimal speeds of walking and running.

(1) There was no significant difference between females and males in the energy cost of standing prior to walking and running, when the values were expressed as Kcals/kg/min.

(2) There was no significant difference between females and males in the energy cost of standing for the total duration of either the walk or the run when the values were expressed as Kcals/kg/km.

(3) The gross and net energy costs of running were significantly greater than those of walking in both females and males. This was true regardless of the units of comparing the energy costs, Kcals/kg/km. or cals/kg/step.

(4) The ratio between the net energy cost of running and walking was approximately equal to the ratio of their respective vertical lifts. This relationship was true regardless of whether the values were expressed in terms of a kilometre of distance travelled or a single step of the activity.

(5) There was no significant difference between females and males in the gross or net energy cost of walking. This was true regardless of the units of comparing the energy costs, Kcals/kg/km. or cals/kg/step.

(6) The gross and net energy costs of running a distance of one kilometre, expressed as Kcals/kg/km., were significantly higher in the females than in the males.

(7) There was no significant difference between females and males in the gross or net energy cost of running a single step when the values were expressed as cals/kg/step.

Recommendations

During the course of this study it was observed that the energy cost of walking and running varied widely between the subjects. It is recommended that further research be undertaken to determine whether physical training would reduce the energy cost of these activities, and if it did, to try and isolate the most trainable segments of the body.

Implications

The results of this study have some implications for those in physical education and other related pursuits.

1) Individuals have different reasons for engaging in physical activity. In certain cases it may be necessary to increase energy expenditure while in others energy conservation may be important. For ex-

ample, an individual, male or female, who is involved in an exercise program for the purpose of weight reduction is interested in maximizing his or her energy expenditure. In this case, running would be more advantageous than walking a given distance at the optimal speed because of the higher energy cost of the former activity. On the other hand, for an individual who is on an extended field trip, it might be necessary to conserve energy. In such a case, it is recommended that, for the same reason, the individual walk rather than run.

2) Individuals who monitor weight loss programs must bear in mind that the energy expended by females and males for a given activity may not be the same. For example, a significantly higher caloric expenditure of running a unit distance by the females implies that, if the total distance run by the females and males was equal, then the former group of subjects would incur a greater weight loss, provided all other factors were identical. On the other hand, if the two groups of subjects were put on an identical walking program, then they would probably incur a similar weight loss because there appears to be no significant difference in the energy cost of walking a unit distance between the two sexes.

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APPENDIX A

CONSENT TO UNDERGO TESTING

CONSENT TO UNDERGO TESTING

I, ________________________________, hereby agree to volunteer in a study designed to determine my metabolic cost of walking and running. I understand that I will:

a) Perform a submaximal oxygen uptake test.

b) Undergo the test to determine my body fat by the densitometry method.

c) Walk and run a distance of one kilometre at a speed that I find most comfortable and that during this walk and run, I will be filmed with a high speed movie camera.

I understand that with any type of exercise there are potential risks and at any time during the test I experience unusual discomfort I will ask to discontinue the test.

In agreeing to such an examination, I waive any legal recourse against the University of Alberta from any and all claims resulting from this fitness test.

Date: ______________________ Subject: ________________________________

(signature)

Witness: ____________________

APPENDIX B

INSTRUCTIONS TO SUBJECTS

Instructions to Subjects for Testing Sessions 3 and 4

In order to increase the reliability of the metabolic measurements that will be determined in sessions 3 and 4, it is necessary that the following precautions be undertaken by you:

1) Avoid ingesting any foods and nutrients for at least 2 hours prior to your scheduled testing time.

2) Avoid vigorous physical activity for at least 2 hours prior to your scheduled testing time. If possible, avoid climbing the staircase on your way to the testing laboratory - use the elevator instead.

3) On entering the testing laboratory, have your body weight taken and then remain seated for 30 minutes on the chair placed beside the treadmill.

APPENDIX C

DATA COLLECTION SHEETS

INFORMATION SHEET

NAME: AGE: YRS. MONTHS

SEX: OCCUPATION:

HEIGHT (With running shoes): Cms. WEIGHT (with gym strip): kgs.

LEG LENGTH: Cms.

TRAINING HABITS:

Prediction of maximal oxygen uptake by the Astrand-Rhyming bicycle ergometer test.

Name: Number:

Mass (kgs): Age (yrs):

Time (mins)	Resistance Kp	Workload kpm/min.	Heart Rate (beats/min)	Mean Heart Rate (mins 5 & 6)	MVO2	
					1/min	ml/kg/min

Age Correction Factor =

Age corrected MVO_2 = 1/min or ml/kg/min.

Determination of percent body fat by the underwater weighing method.

Name: Sex: Number:

Measurements:

(1) Weight in air =
(2) Vital Capacity (V.C.) = litres x 61.02 = cu. ins.
(3) Residual Volume = 25% or 30% V.C. = cu. ins.
(4) Volume of Gastro intestinal track (V.G.I.) = 7.01 cu. ins.
(5) Weight in water = $\frac{\text{Chart Reading x belt weight}}{75}$ - belt weight
= lbs.

Calculations:

(6) Total body air (T.B.A.) = V.C. + R.V. + V.G.I. (from 2,3 and 4 above)
= x .0362 = lbs.
(7) True weight in water = weight in water (5) + total body air (6)
= (lbs)
(8) Body volume = weight in air (1) - true weight in water (7)
=
(9) Body density = $\frac{\text{weight in air (1)}}{\text{body volume (8)}}$ x density of water at ^{o}C.
=
(10) Percent Fat = $\frac{4.570}{\text{Body density (a)}}$ - 4.142 x 100
= %
(11) Pounds fat = percent fat (10) x Wt. in air (1)
= lbs.
(12) Fat free weight = weight in air (1) - pounds fat (11)
= lbs.

<u>Characteristics of the Optimal Walk/Run</u>

Name: Sex: Number:

Age (months): Mass:* lbs. kgs.

Height (cms):* Leg Length (cms):* $\frac{\text{Height}}{\text{Leg Length}}$

Activity: Walking/Running

Optimal Speed: kmh or m/min.

Time to Walk/Run 1 kilometre:

Treadmill Setting (% rpm):

	1	2	Mean (steps/min)
Step Frequency			

Step Frequency per Kilometre = Time to Walk/Run 1 kilometre x Mean steps per minute

	1	2	3	4	5	6	Mean(Lift/step)
Vertical Lift (cms)							

Vertical Lift per Kilometere = Step Frequency per Kilometre x Mean Vertical Lift per Step

*With running shoes.

APPENDIX D

TABLES USED FOR CONVERTING OXYGEN CONSUMPTION VALUES INTO KILOCALORIC EQUIVALENTS

Tables[1] used for converting oxygen consumption values into Kilocaloric equivalents.

Non-protein R.Q.	Kilocalories per litre of Oxygen
0.70	4.686
0.71	4.694
0.72	4.702
0.73	4.7145
0.74	4.727
0.75	4.7395
0.76	4.752
0.77	4.764
0.78	4.776
0.79	4.7885
0.80	4.801
0.81	4.813
0.82	4.825
0.83	4.8375
0.84	4.850
0.85	4.8625
0.86	4.875
0.87	4.8875
0.88	4.900
0.89	4.914
0.90	4.928
0.91	4.938
0.92	4.948
0.93	4.9605
0.94	4.973
0.95	4.985
0.96	4.997
0.97	5.0095
0.98	5.022
0.99	5.0345
1.00	5.047

[1] From, Carpenter, T.M.; Tables, Factors and Formulas for Computing Respiratory Exchange and Biological Transformation of Energy; 3rd edition, Washington, Carnegie Institute of Washington, 1939.

APPENDIX E

CHARACTERISTICS OF SUBJECTS

Table 46- Characteristics of Female Subjects

Subject Number	Age (months)	Height (cms.)	Leg Length (cms.)	Height / Leg Length	Mass (kgs.) 1*	Mass (kgs.) 2**	Percent Fat	Lean Body Mass (kgs)	Fat Body Mass (kgs)	Predicted VO_2 (ml/kg/min)
1	271	162.50	102.00	1.593	55.6	54.8	18.56	44.60	10.20	46.74
2	264	162.50	99.50	1.633	59.3	58.3	17.34	48.20	10.10	42.30
3	267	170.20	103.20	1.649	62.2	59.5	19.98	47.62	11.88	44.60
4	280	167.60	102.90	1.629	56.2	55.6	14.10	47.75	7.85	60.42
5	219	168.90	105.40	1.602	50.5	49.1	13.12	42.65	6.45	68.45
6	252	172.70	110.00	1.570	61.8	61.3	18.15	50.20	11.10	40.29
7	255	173.40	109.25	1.587	65.6	64.5	22.28	50.10	14.40	53.50
8	228	166.40	103.10	1.613	51.4	52.9	10.91	47.10	5.80	55.83
9	229	160.60	106.00	1.587	53.8	51.4	18.97	41.65	9.75	65.33
10	245	168.30	106.00	1.587	64.5	61.8	20.62	49.05	12.75	55.87
11	241	165.10	105.00	1.572	63.8	62.9	23.24	48.30	14.60	42.96
12	261	161.90	104.10	1.555	50.8	48.2	10.91	42.95	5.25	44.90
Mean	251	166.68	104.70	1.598	57.96	56.69	17.35	46.68	10.01	51.76

*Mean mass at time of test walk and test run (sessions 3 and 4) - subject wearing gym. strip and running shoes
*Mass measured at the time of determination of percent body fat (session 1).

Table 47- Characteristics of Male Subjects

Subject Number	Age (months)	Height (cms.)	Leg Length (cms.)	Height / Leg Length	Mass (kgs.) 1*	Mass (kgs.) 2**	Percent Fat	Lean Body Mass (kgs)	Fat Body Mass (kgs)	Predicted VO_2 (ml/kg/min)
1	252	170.20	103.50	1.644	71.2	67.25	9.85	60.65	6.60	66.51
2	287	172.70	104.10	1.658	71.7	71.5	9.73	64.55	6.95	68.10
3	300	181.60	111.75	1.625	79.2	78.7	10.88	70.15	8.55	50.28
4	271	169.50	102.10	1.660	68.3	66.75	9.73	60.25	6.50	45.71
5	306	167.60	105.40	1.591	56.6	55.9	9.21	50.75	5.15	68.10
6	257	181.60	109.20	1.663	71.9	70.1	6.84	65.30	4.80	56.12
7	245	183.50	108.60	1.690	75.5	75.4	7.93	69.45	5.95	49.50
8	378	177.80	109.20	1.628	75.8	72.75	14.66	62.10	10.65	45.50
9	289	179.10	109.30	1.639	68.3	67.35	6.72	62.85	4.50	52.69
10	257	179.10	110.75	1.617	80.1	78.65	7.31	72.90	5.75	51.43
11	291	165.10	99.10	1.667	57.4	55.45	14.10	47.65	7.80	57.31
12	281	177.80	109.60	1.622	69.6	68.6	7.50	63.45	5.15	62.30
Mean	284.5	175.50	106.88	1.642	70.46	69.03	9.54	62.50	6.53	56.12

*Mean mass at time of test walk and test run (sessions 3 and 4)-subject wearing gym. strip and running shoes.
*Mass measured at the time of determination of percent body fat (session 1).

APPENDIX F

RAW DATA

Table 48- The Energy Cost of Standing prior to Walking and Running in Females

Subject	Walking					Running				
	Oxygen Consumption		R.Q.	Energy Cost		Oxygen Consumption		R.Q.	Energy Cost	
Number	ml/min.	ml/kg/min.		Kcals/min.	Kcals/kg/min.	ml/min.	ml/kg/min.		Kcals/min.	Kcals/kg/min.
1	179	3.3	0.84	0.8692	0.0158	210	3.8	0.85	1.0220	0.0182
2	283	4.8	0.87	1.3798	0.0234	249	4.2	0.87	1.2182	0.0204
3	253	4.1	0.75	1.1998	0.0194	262	4.2	0.78	1.2522	0.0202
4	263	4.7	0.79	1.2594	0.0226	264	4.7	0.71	1.2408	0.0222
5	153	3.1	0.77	0.7284	0.0146	192	3.7	0.86	0.9372	0.0182
6	230	3.8	0.79	1.1002	0.0180	257	4.1	0.74	1.2148	0.0196
7	242	3.7	0.84	1.1718	0.0178	267	4.1	0.78	1.2754	0.0194
8	196	3.8	0.79	0.9384	0.0184	154	3.0	0.81	0.7398	0.0144
9	273	5.1	0.83	1.3218	0.0246	242	4.4	0.80	1.1610	0.0214
10	208	3.2	0.76	0.9894	0.0154	240	3.8	0.77	1.1444	0.0180
11	272	4.2	0.72	1.2798	0.0200	313	5.0	0.76	1.4888	0.0238
12	198	3.9	0.74	0.9354	0.0186	231	4.5	0.74	1.0924	0.0214
Mean	229.2	3.98	0.79	1.0978	0.0190	240.1	4.13	0.79	1.1488	0.0198

Table 49 - The Energy Cost of Standing prior to Walking and Running in Males

Subject	Walking					Running				
	Oxygen Consumption		R.Q.	Energy Cost		Oxygen Consumption		R.Q.	Energy Cost	
Number	ml/min.	ml/kg/min.		Kcals/min.	Kcals/kg/min.	ml/min.	ml/kg/min.		Kcals/min.	Kcals/kg/min.
1	297	4.1	0.80	1.4272	0.0198	305	4.2	0.74	1.4432	0.0202
2	319	4.4	0.75	1.5118	0.0208	293	4.0	0.78	1.3988	0.0194
3	290	3.7	0.97	1.4514	0.0184	323	4.1	0.79	1.5452	0.0194
4	269	4.0	0.75	1.2762	0.0188	247	3.6	0.82	1.1914	0.0174
5	253	4.5	0.93	1.2534	0.0220	287	5.1	0.74	1.3576	0.0240
6	348	4.8	0.75	1.6514	0.0230	237	3.3	0.96	1.1810	0.0164
7	390	5.2	0.77	1.8588	0.0246	390	5.2	0.77	1.8588	0.0246
8	312	4.1	0.78	1.4912	0.0196	172	2.3	0.79	0.8202	0.0149
9	279	4.1	0.90	1.3732	0.0200	334	4.9	0.79	1.5994	0.0234
10	279	3.5	0.77	1.3290	0.0168	321	4.0	0.94	1.5902	0.0198
11	224	3.9	0.80	1.0760	0.0190	241	4.1	0.86	1.1756	0.0200
12	383	5.5	0.87	1.8714	0.0268	370	5.3	0.78	1.7652	0.0254
Mean	303.6	4.32	0.81	1.4642	0.0208	293.33	4.18	0.80	1.4106	0.0202

Table 50- Characteristics of the Optimal Walking Speed of Female Subjects

Subject	Optimal Speed		Time to	Step Frequency		Step	Vertical Lift	
Number	kmh	metres/min.	Walk 1 km. (mins:secs)	steps/km.	steps/min.	Length cms/step	Lift/step cms.	Lift/km. cms.
1	3.9751	66.25	15:06	1502	99.5	66.58	2.34	3514.68
2	4.4803	74.67	13:24	1548	115.5	64.60	2.34	3622.32
3	4.7329	78.88	12:41	1427	112.5	70.08	3.05	4352.35
4	4.2277	70.46	14:12	1619	114	61.76	2.52	4079.88
5	5.1849	86.41	11:34	1359	117.5	73.58	4.78	6496.02
6	4.9589	82.65	12:06	1307	108	76.51	3.03	3960.21
7	4.9589	82.65	12:06	1307	108	76.51	3.25	4247.75
8	4.7329	78.88	12:41	1325	104.5	75.47	4.13	5472.25
9	4.7329	78.88	12:41	1478	116.5	67.66	3.79	5601.62
10	4.4803	74.67	13:24	1501	112	66.62	2.86	4292.86
11	4.4803	74.67	13:24	1461	109	68.44	2.93	4280.73
12	4.7329	78.88	12:41	1478	116.5	67.66	2.82	4167.96
Mean	4.6398	77.33	13:00	1442.66	111.1	69.62	3.15	4507.39

Table 51- Characteristics of the Optimal Running Speed of Female Subjects

Subject	Optimal Speed		Time to Run 1 km.	Step Frequency		Step Length	Vertical Lift	
Number	kmh	metres/min	(mins:secs)	steps/km.	steps/min.	cms/step	Lift/step cms.	Lift/km. cms.
1	8.4090	140.15	7:08	1140	159.5	87.72	9.33	10636.20
2	8.8743	147.91	6:46	1062	157	94.16	7.75	8230.50
3	8.6416	144.03	6:57	1011	145.5	98.91	10.70	10817.70
4	7.9769	132.95	7:31	1244	165.5	80.39	7.71	9591.24
5	8.4090	140.15	7:08	1173	164.5	85.25	9.05	10615.65
6	9.1069	151.78	6:35	1014	154	98.62	10.93	11083.02
7	9.5323	158.87	6:18	967	153.5	103.41	8.34	8064.78
8	8.6416	144.03	6:57	1004	144.5	99.60	8.88	8915.52
9	8.6416	144.03	6:57	1164	167.5	85.91	7.04	8194.56
10	8.6416	144.03	6:57	1143	164.5	87.49	8.35	9544.05
11	8.1763	136.27	7:20	1093	149	91.49	10.16	11104.88
12	8.4090	140.15	7:08	1159	162.5	86.28	8.47	9816.73
Mean	8.6211	143.69	6:58	1097.83	157.3	91.60	8.89	9717.90

Table 52– Characteristics of the Optimal Walking Speed of Male Subjects

Subject	Optimal Speed		Time to Walk 1 km.	Step Frequency		Step Length	Vertical Lift	
Number	kmh	metres/min	(mins:secs)	steps/km.	steps/min.	cms/step	Lift/step cms.	Lift/km. cms.
1	4.7329	78.88	12:41	1478	116.5	67.66	2.86	4227.08
2	5.3976	89.96	11:07	1273	114.5	78.55	2.77	3526.21
3	4.7329	78.88	12:41	1275	100.5	78.43	3.23	4118.25
4	3.9751	66.25	15:06	1563	103.5	63.98	2.97	4642.11
5	4.7329	78.88	12:41	1370	108	72.99	2.83	3877.10
6	5.1849	86.42	11:34	1319	114	75.82	3.16	4168.04
7	5.1849	86.42	11:34	1261	109	79.30	4.70	5926.70
8	5.1849	86.42	11:34	1243	107.5	80.45	3.58	4449.94
9	5.3976	89.96	11:07	1251	112.5	79.94	4.06	5079.06
10	4.9589	82.65	12:06	1307	108	76.51	2.99	3907.93
11	4.4803	74.67	13:24	1434	107	69.74	3.01	4316.34
12	4.7329	78.88	12:41	1434	113	69.74	3.54	5076.36
Mean	4.8913	81.46	12:21	1350.66	109.5	74.43	3.31	4442.93

Table 53- Characteristics of the Optimal Running Speed of Male Subjects

Subject Number	Optimal Speed kmh	Optimal Speed metres/min	Time to Run 1 km. (mins:secs)	Step Frequency steps/km.	Step Frequency steps/min.	Step Length cms/step	Vertical Lift Lift/step cms.	Vertical Lift Lift/km. cms.
1	8.8743	147.91	6:46	1184	175	84.45	8.06	9543.04
2	9.5323	158.87	6:18	1115	177	89.69	6.10	6801.50
3	8.8743	147.91	6:46	1022	151	97.85	8.41	8595.02
4	9.1069	151.78	6:35	1096	166.5	91.24	8.29	9085.84
5	8.8743	147.91	6:46	1039	153.5	96.24	8.50	8831.5
6	9.7384	162.30	6:10	894	145	111.86	11.49	10272.06
7	9.3196	155.33	6:26	1026	159.5	97.47	10.65	10926.90
8	9.3196	155.33	6:26	1078	167.5	92.76	8.59	9260.02
9	9.5323	158.87	6:18	970	154	103.09	10.28	9971.60
10	9.7384	162.30	6:10	974	158	102.66	7.75	7548.50
11	7.7774	129.62	7:43	1208	156.5	82.78	7.95	9603.60
12	10.8352	180.59	5:32	905	163.5	110.50	9.51	8606.55
Mean	9.2936	154.89	6:30	1025.91	160.6	96.71	8.80	9087.17

Table 54 - Gross Energy Cost of Walking One Kilometre of Female Subjects

Subject	Walking Speed		Walking Time	Recovery Time	Total Oxygen Consumption				Mean	Gross Energy Cost	
					During Walk		During Recovery				
Number	kmh	metres/min.	mins:secs.	mins:secs.	ml	ml/kg	ml	ml/kg	R.Q.	Kcals/Km.	Kcals/Kg/Km.
1	3.9751	66.25	15:06	2:54	8534	154.90	706	12.7	0.89	45.3219	0.8221
2	4.4803	74.67	13:24	1:36	10346	173.45	694	11.7	0.83	53.4070	0.8957
3	4.7329	78.88	12:41	1:49	9720	156.30	730	11.7	0.80	50.0934	0.8053
4	4.2277	70.46	14:12	1:48	8960	159.65	675	12.0	0.80	46.2695	0.8243
5	5.1849	86.41	11:34	4:56	7093	143.20	1082	22.0	0.81	39.3357	0.7949
6	4.9589	82.65	12:06	2:24	9425	152.75	830	13.5	0.81	49.3035	0.7993
7	4.9589	82.65	12:06	3:54	9219	144.85	1286	17.8	0.82	50.6369	0.7841
8	4.7329	78.88	12:41	2:19	6221	122.10	574	11.4	0.81	32.7295	0.6430
9	4.7329	78.88	12:41	1:49	8905	166.85	560	10.5	0.89	46.5029	0.8713
10	4.4803	74.67	13:24	3:36	10000	153.75	1190	18.4	0.82	54.0563	0.8316
11	4.4803	74.67	13:24	2:06	11816	184.4	899	14.0	0.87	62.2782	0.9718
12	4.7329	78.88	12:41	2:49	7826	155.0	849	16.8	0.80	41.6554	0.8250
Mean	4.6398	77.33	13:00	2:40	9005	155.6	840	14.4	0.83	47.6324	0.8224

Table 55 - Gross Energy Cost of Running One Kilometre of Female Subjects

Subject	Running Speed		Running Time	Recovery Time	Total Oxygen Consumption				Mean	Gross Energy Cost	
					During Run		During Recovery				
Number	kmh	metres/min.	mins:secs.	mins:secs.	ml	ml/kg	ml	ml/kg	R.Q.	Kcals/Km.	Kcals/Kg/Km.
1	8.4090	140.15	7:08	5:52	11288	201.0	2632	46.8	0.98	69.7499	1.2417
2	8.8743	147.91	6:46	6:44	13482	228.1	4133	69.9	1.04	88.2465	1.4932
3	8.6416	144.03	6:57	3:33	12590	202.6	2130	34.3	0.99	73.7503	1.1869
4	7.9769	132.95	7:31	4:29	11611	206.5	1974	35.1	0.81	65.3456	1.1619
5	8.4090	140.15	7:08	3:22	9786	190.2	1419	27.6	0.91	55.1358	1.0717
6	9.1069	151.78	6:35	8:25	14658	234.6	3993	66.9	0.83	90.3887	1.4612
7	9.5323	158.87	6:18	5:12	12187	185.8	2858	43.60	0.85	72.9501	1.1125
8	8.6416	144.03	6:57	10:03	11282	217.8	3108	60.0	0.92	71.2603	1.3754
9	8.6416	144.03	6:57	4:03	10079	186.0	1576	29.0	0.86	56.8383	1.0487
10	8.6416	144.03	6:57	10:03	13603	210.8	3147	50.6	1.03	84.2599	1.3150
11	8.1763	136.27	7:20	7:10	15202	243.2	4353	69.7	0.85	95.2735	1.5247
12	8.4090	140.15	7:08	12:52	13737	269.3	5788	113.3	0.84	95.5355	1.8721
Mean	8.6211	143.69	6:58	6:49	12459	214.7	3093	53.9	0.91	76.5611	1.3221

Table 56 - Gross Energy Cost of Walking One Kilometre of Male Subjects

Subject	Walking Speed		Walking Time	Recovery Time	Oxygen Consumption				Mean	Gross Energy Cost	
					During Walk		During Recovery				
Number	kmh	metres/min.	mins:secs.	mins:secs.	ml	ml/kg	ml	ml/kg	R.Q.	Kcals/Km.	Kcals/Kg/Km.
1	4.7329	78.88	12:41	2:49	10058	141.8	903	12.7	1.05	55.0430	0.7759
2	5.3976	89.96	11:07	3:23	11526	161.1	1369	19.1	0.80	61.7879	0.8634
3	4.7329	78.88	12:41	2:49	10644	135.0	1011	12.8	0.99	58.3570	0.7403
4	3.9751	66.25	15:06	2:54	11322	166.55	968	14.3	0.78	58.6371	0.8629
5	4.7329	78.88	12:41	1:49	8599	152.5	594	10.5	0.89	44.9860	0.7976
6	5.1849	86.42	11:34	1:56	11897	165.3	949	13.2	0.80	61.6000	0.8560
7	5.1849	86.42	11:34	1:26	9622	127.0	593	7.8	1.06	51.5550	0.6803
8	5.1849	86.42	11:34	1:26	11670	153.2	635	8.3	0.82	59.3267	0.7789
9	5.3976	89.96	11:07	1:53	9578	143.7	727	10.7	0.93	50.9178	0.7431
10	4.9589	82.65	12:06	2:54	13785	173.3	1230	15.5	0.83	72.5766	0.9123
11	4.4803	74.67	13:24	1:36	7658	135.8	462	8.2	0.84	39.3744	0.6985
12	4.7329	78.88	12:41	1:49	11034	159.2	931	12.6	0.82	57.7099	0.8286
Mean	4.8913	81.46	12:21	2:14	10616	151.2	864	12.1	0.86	55.9893	0.7948

Table 57 - Gross Energy Cost of Running One Kilometre of Male Subjects

Subject	Running Speed		Running Time	Recovery Time	Total Oxygen Consumption				Mean	Gross Energy Cost	
					During Run		During Recovery				
Number	kmh	metres/min.	mins:secs.	mins:secs.	ml	ml/kg	ml	ml/kg	R.Q.	Kcals/Km.	Kcals/Kg/Km.
1	8.8743	147.91	6:46	4:44	13383	187.6	2722	38.1	0.86	78.2967	1.0970
2	9.5323	158.87	6:18	5:42	11913	165.7	2822	39.3	1.08	74.1864	1.0319
3	8.8743	147.91	6:46	3:44	14973	188.2	2502	31.5	0.87	85.4362	1.0741
4	9.1069	151.78	6:35	6:25	11357	165.7	2608	38.0	1.00	69.7598	1.0175
5	8.8743	147.91	6:46	3:14	13974	246.4	1776	33.3	0.84	76.4075	1.3572
6	9.7384	162.30	6:10	4:20	14293	199.5	2722	37.7	1.04	85.6805	1.1942
7	9.3196	155.33	6:26	2:04	15904	211.6	2001	26.6	0.86	86.9141	1.1563
8	9.3196	155.33	6:26	10:34	13289	176.3	3831	50.8	0.87	83.6254	1.1090
9	9.5323	158.87	6:18	5:12	14896	219.1	3149	46.1	0.82	87.2122	1.2817
10	9.7384	162.30	6:10	11:20	15607	193.5	5893	73.2	1.08	108.2179	1.3424
11	7.7774	129.62	7:43	2:47	11849	203	1151	19.8	0.83	63.0085	1.0799
12	10.8352	180.59	5:32	6:28	12534	180.2	4011	58.0	0.88	81.5281	1.1737
Mean	9.2936	154.89	6:30	5:33	13664	194.7	2932	40.7	0.91	79.1252	1.1596

Table 58 - The Net Energy Cost of Walking One Kilometre of Female Subjects

Subject	Total Time	Gross Energy Cost		Standing Energy Cost				Net Energy Cost	
Number	mins:secs.	Kcals/Km.	Kcals/kg/km.	Kcals/min.	Kcals/kg/min.	Kcals/km.	Kcals/kg/km.	Kcals/km.	Kcals/kg/km.
1	18:00	45.3219	0.8221	0.8692	0.0158	15.6456	0.2844	29.6772	0.5363
2	15:00	53.4070	0.8957	1.3798	0.0234	20.6970	0.3510	32.7097	0.5461
3	14:30	50.0934	0.8053	1.1998	0.0194	17.3971	0.2813	32.6951	0.5241
4	16:00	46.2695	0.8243	1.2594	0.0226	20.1504	0.3616	26.1189	0.4642
5	16:30	39.3357	0.7949	0.7284	0.0146	12.0186	0.2409	27.3165	0.5537
6	14:30	49.3035	0.7993	1.1002	0.0180	15.9529	0.2610	33.3509	0.5385
7	16:00	50.6369	0.7841	1.1718	0.0178	18.7488	0.2848	31.8867	0.4982
8	15:00	32.7295	0.6430	0.9384	0.0184	14.0760	0.2760	18.6545	0.3665
9	14:30	46.5029	0.8713	1.3218	0.0246	19.1661	0.3567	27.3379	0.5133
10	17:00	54.0563	0.8316	0.9894	0.0154	16.8198	0.2618	37.2359	0.5688
11	15:30	62.2782	0.9718	1.2798	0.0200	19.8369	0.3100	42.4413	0.6626
12	15:30	41.6554	0.8250	0.9354	0.0186	14.4987	0.2883	27.1567	0.5379
Mean	15:40	47.6324	0.8224	1.0978	0.0190	17.0840	0.2965	30.5484	0.5258

Table 59 - The Net Energy Cost of Running One Kilometre of Female Subjects

Subject	Total Time	Gross Energy Cost		Standing Energy Cost				Net Energy Cost	
Number	mins:secs.	Kcals/Km.	Kcals/kg/km.	Kcals/min.	Kcals/kg/min.	Kcals/Km.	Kcals/kg/km.	Kcals/Km.	Kcals/kg/km.
1	13:00	69.7499	1.2417	1.0220	0.0182	13.2860	0.2366	56.4651	1.0038
2	13:30	88.2465	1.4932	1.2182	0.0204	16.4457	0.2754	71.8011	1.2171
3	10:30	73.7503	1.1869	1.2522	0.0202	13.1481	0.2121	60.6023	0.9756
4	12:00	65.3456	1.1619	1.2408	0.0222	14.8896	0.2664	50.4552	0.8957
5	10:30	55.1358	1.0717	0.9372	0.0182	9.8406	0.1911	45.2958	0.8800
6	15:00	90.3887	1.4612	1.2148	0.0196	18.2220	0.2940	72.1660	1.1670
7	11:30	72.9501	1.1125	1.2754	0.0194	14.6671	0.2231	58.2838	0.8884
8	17:00	71.2603	1.3754	0.7398	0.0144	12.5766	0.2448	58.6825	1.1320
9	11:00	56.8383	1.0487	1.1610	0.0214	12.7710	0.2354	44.0663	0.8139
10	17:00	84.2599	1.3150	1.1444	0.0180	19.4548	0.3060	64.8064	1.0102
11	14:30	95.2735	1.5247	1.4888	0.0238	21.5876	0.3451	73.6857	1.1792
12	20:00	95.5355	1.8721	1.0924	0.0214	21.8480	0.4280	73.6880	1.4427
Mean	13:47	76.5611	1.3221	1.1488	0.0198	15.7281	0.2715	60.8331	1.0505

Table 60 - The Net Energy Cost of Walking One Kilometre of Male Subjects

Subject Number	Total Time mins:secs.	Gross Energy Cost		Standing Energy Cost				Net Energy Cost	
		Kcals/Km.	Kcals/kg/km.	Kcals/min.	Kcals/kg/min.	Kcals/Km.	Kcals/kg/km.	Kcals/Km.	Kcals/kg/km.
1	15:30	55.0430	0.7759	1.4272	0.0198	22.1216	0.3069	32.9222	0.4676
2	14:30	61.7879	0.8634	1.5118	0.0208	21.9211	0.3016	39.8677	0.5618
3	15:30	58.3570	0.7403	1.4514	0.0184	22.4967	0.2852	35.8598	0.4564
4	18:00	58.6371	0.8629	1.2762	0.0188	22.9716	0.3384	35.6645	0.5247
5	14:30	44.9860	0.7976	1.2534	0.0220	18.1743	0.3190	26.8127	0.4773
6	13:30	61.6000	0.8560	1.6514	0.0230	22.2939	0.3105	39.3053	0.5453
7	13:00	51.5550	0.6803	1.8588	0.0246	24.1644	0.3198	27.3906	0.3594
8	13:00	59.3267	0.7789	1.4912	0.0196	19.3856	0.2548	39.9412	0.5248
9	13:00	50.9178	0.7431	1.3732	0.0200	17.8516	0.2600	33.0670	0.4834
10	15:00	72.5766	0.9123	1.3290	0.0168	19.9350	0.2520	52.6424	0.6616
11	15.00	39.3744	0.6985	1.0760	0.0190	16.1400	0.2850	23.2350	0.4139
12	14:30	57.7099	0.8286	1.8714	0.0268	27.1353	0.3886	30.5758	0.4404
Mean	14:35	55.9893	0.7948	1.4642	0.0208	21.2159	0.3018	34.7736	0.4931

Table 61 - The Net Energy Cost of Running One Kilometre of Male Subjects

Subject	Total Time	Gross Energy Cost		Standing Energy Cost				Net Energy Cost	
Number	mins:secs.	Kcals/Km.	Kcals/kg/km.	Kcals/min.	Kcals/kg/min.	Kcals/km.	Kcals/kg/km.	Kcals/Km.	Kcals/kg/km.
1	11:30	78.2967	1.0970	1.4432	0.0202	16.5968	0.2323	61.7005	0.8658
2	12:00	74.1864	1.0319	1.3988	0.0194	16.7856	0.2328	57.4008	0.7999
3	10:30	85.4362	1.0741	1.5452	0.0194	16.2246	0.2037	69.2115	0.8697
4	13:00	69.7598	1.0175	1.1914	0.0174	15.4882	0.2262	54.2713	0.7912
5	10:00	76.4075	1.3572	1.3576	0.0240	13.5760	0.2400	62.8318	1.1178
6	10:30	85.6805	1.1942	1.1810	0.0164	12.4005	0.1722	73.2800	1.0210
7	8:30	86.9141	1.1563	1.8588	0.0246	15.7998	0.2091	71.1143	0.9464
8	17:00	83.6254	1.1090	0.8202	0.0110	13.9434	0.1870	69.6811	0.9226
9	17:30	87.2122	1.2817	1.5994	0.0234	27.9895	0.3978	68.8190	1.0130
10	16:30	108.2179	1.3424	1.5902	0.0198	26.2383	0.3267	80.3887	0.9948
11	10:30	63.0085	1.0799	1.1756	0.0200	12.3438	0.2100	50.6642	0.8688
12	12:00	81.5281	1.1737	1.7652	0.0254	21.1824	0.3048	60.3466	0.8681
Mean	12:03	81.6894	1.1596	1.4106	0.0202	17.3807	0.2452	64.9758	0.9233

Table 62- The Gross and Net Energy Cost per Step of Walking and Running in Female Subjects

	Walking					Running				
Subject Number	Step Frequency Steps/km.	Gross Energy Cost		Net Energy Cost		Step Frequency Steps/km.	Gross Energy Cost		Net Energy Cost	
		Kcals/kg /km	*cals/kg /step	Kcals/kg /km	*cals/kg /step		Kcals/kg /km	*cals/kg /step	Kcals/kg /km	*cals/kg /step
1	1502	0.8221	0.5473	0.5363	0.3571	1140	1.2417	1.0892	1.0038	0.8805
2	1548	0.8957	0.5786	0.5461	0.3528	1062	1.4932	1.4060	1.2171	1.1460
3	1427	0.8053	0.5643	0.5241	0.3673	1011	1.1869	1.1740	0.9756	0.9650
4	1619	0.8243	0.5091	0.4642	0.2867	1244	1.1619	0.9340	0.8957	0.7200
5	1359	0.7949	0.5849	0.5537	0.4074	1173	1.0717	0.9136	0.8800	0.7502
6	1307	0.7993	0.6115	0.5385	0.4120	1014	1.4612	1.4410	1.1670	1.1510
7	1307	0.7841	0.5999	0.4982	0.3812	967	1.1125	1.1505	0.8884	0.9187
8	1325	0.6430	0.4853	0.3665	0.2766	1004	1.3754	1.3699	1.1320	1.1275
9	1478	0.8713	0.5895	0.5133	0.3473	1164	1.0487	0.9009	0.8139	0.6992
10	1501	0.8316	0.5540	0.5688	0.3789	1143	1.3154	1.1508	1.0102	0.8838
11	1461	0.9718	0.6652	0.6626	0.4535	1093	1.5247	1.3950	1.1792	1.0789
12	1478	0.8250	0.5582	0.5379	0.3639	1159	1.8721	1.6153	1.4427	1.2448
Mean	1442.66	0.8224	0.5707	0.5258	0.3654	1097.83	1.3221	1.2117	1.0505	0.9638

* 1 gram calorie (abbreviated as cals) is equivalent to 0.001 Kilocalorie.

Table 63 - The Gross and Net Energy Cost per Step of Walking and Running in Male Subjects

	Walking					Running				
Subject Number	Step Frequency Steps/km.	Gross Energy Cost		Net Energy Cost		Step Frequency Steps/km.	Gross Energy Cost		Net Energy Cost	
		Kcals/kg /km	*cals/kg /step	Kcals/kg /km	*cals/kg /step		Kcals/kg /km	*cals/kg /step	Kcals/kg /km	*cals/kg /step
1	1478	0.7759	0.5250	0.4676	0.3164	1184	1.0970	0.9265	0.8658	0.7313
2	1273	0.8634	0.6782	0.5618	0.4413	1115	1.0319	0.9255	0.7999	0.7174
3	1275	0.7403	0.5806	0.4564	0.3580	1022	1.0741	1.0510	0.8697	0.8510
4	1563	0.8629	0.5521	0.5247	0.3357	1096	1.0175	0.9284	0.7912	0.7219
5	1370	0.7976	0.5822	0.4773	0.3484	1039	1.3572	1.3063	1.1178	1.0758
6	1319	0.8560	0.6490	0.5453	0.4134	894	1.1942	1.3358	1.0210	1.1421
7	1261	0.6803	0.5395	0.3594	0.2850	1026	1.1563	1.1270	0.9464	0.9224
8	1243	0.7789	0.6266	0.5248	0.4222	1078	1.1090	1.0288	0.9226	0.8558
9	1251	0.7431	0.5940	0.4834	0.3864	970	1.2817	1.3213	1.0130	1.0443
10	1307	0.9123	0.6980	0.6616	0.5062	974	1.3424	1.3782	0.9948	1.0214
11	1434	0.6985	0.4871	0.4139	0.2886	1208	1.0799	0.8940	0.8688	0.7192
12	1434	0.8286	0.5778	0.4404	0.3071	905	1.1737	1.2970	0.8681	0.9592
Mean	1350.66	0.7948	0.5938	0.4931	0.3673	1025.91	1.1596	1.1267	0.9233	0.8968

* 1 gram calorie (abbreviated as cals) is equivalent to 0.001 Kilocalorie.